APPLICATION NO. 09/826,117

INVENTORS: Urbain Alfred von der Embse

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~~Complex~~ Hybrid Walsh ~~Codes~~ encoder and decoder for CDMA

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STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

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APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hybrid ~~Complex~~ Walsh encoder and decoder ~~Codes~~ for CDMA

INVENTOR~~S~~: Urbain Alfred von der Embse

BACKGROUND OF THE INVENTION

I. Field of the Invention

~~**TECHNICAL FIELD**~~

The present invention relates to CDMA (Code Division Multiple Access) cellular telephone and wireless data communications with data rates up to multiple T1 (1.544 Mbps) and higher (>100 Mbps), and to optical CDMA with data rates in the Gbps and higher ranges. Applications are mobile, point-to-point and satellite communication networks. More specifically the present invention relates to novel ~~complex and h~~Hybrid complex Walsh codes developed to replace current real Walsh orthogonal CDMA channelization codes.

~~**CONTENTS**~~

II. Description of the Related Art

~~**BACKGROUND ART**~~

~~Current~~ CDMA art is represented by the recent work on multiple access for broadband wireless communications~~, ~~ which includes ~~the G3 (third generation CDMA) proposed standard candidates, the current IS-95 CDMA standard, the early Qualcomm patents, and the real Walsh technology. These are documented in references 1,2,3,4,5,6. Reference 1 is an issue of the IEEE communications magazine devoted to multiple access communications for broadband wireless networks, reference 2 is an issue on IEEE personal communications devoted to the third generation (3G) mobile systems in Europe~~"Multiple Access for Broadband Networks", IEEE Communications magazine July 2000 Vol. 38 No. 7, "Third Generation Mobile Systems in Europe", IEEE Personal Communications April 1998 Vol. 5 No. 2 ~~reference 3 is the~~ , IS-95/IS-95A, ~~standard primarily developed by Qualcomm, references 4 and 5 are Qualcomm patents addressing the use of real Walsh orthogonal CDMA codes, and reference 6 is the widely used reference on real Walsh technology.~~ , the IS-95/IS-95A, the 3G CDMA2000 and W-CDMA, and the listed patents.

Current art using real Walsh orthogonal CDMA channelization codes ~~is represented by the scenario described in the following with the aid of equations (1) and FIG 1,2,3,4. This scenario~~ considers CDMA communications spread over a common frequency band for each of the communication channels. These CDMA communications channels for each of the users are defined by assigning a unique Walsh orthogonal spreading codes to each user. The Walsh code for each user spreads the user data symbols over the common frequency band. These Walsh encoded user signals are summed and re-spread over the same frequency band by one or more PN (pseudo-noise) codes, to generate the CDMA communications

signal which is modulated and transmitted. The communications link consists of a transmitter, propagation path, and receiver, as well as interfaces and control.

~~It is assumed that the communication link is in the communications mode with all of the users communicating at the same symbol rate and the synchronization is sufficiently accurate and robust to support this communications mode. In addition, the possible power differences between the users is assumed to be incorporated in the data symbol amplitudes prior to the CDMA encoding in the CDMA transmitter, and the power is uniformly spread over the wideband by proper selection of the CDMA pulse waveform. It is self evident to anyone skilled in the CDMA communications art that these communications mode assumptions are both reasonable and representative of the current CDMA art and do not limit the applicability of this invention.~~

Transmitter ~~equations~~ Equation **(1)** describes a representative real Walsh CDMA encoding for the transmitter in FIG. **1A,1B.1C**. It is assumed that there are N Walsh code vectors W(u) each of length N chips **1**. The code vector is presented by a 1xN N-chip row vector W(u)=[W(u,1),…,W(u,N)] where W(u,n) is chip n of code u. The code vectors are the row vectors of the Walsh matrix W. Walsh code chip n of code vector u has the possible values W(u,n)= +/-1. Each user is assigned a unique Walsh code which allows the code vectors to be designated by the user symbols u=0,1,…,N-1 for N Walsh codes. User data symbols **2** are the set of complex symbols {Z(u), u=0,,1,…,N-1) and the set of equivalent real symbols $(R(u_R), I(\cancel{U_I}u_I), u_R, u_I =0,1,…,N-1\}$ since Z=R+jI for all u, where j=√-1 and u_R, u_I refer to different users assigned to the same real Walsh code vector u. ~~where Z is a complex symbol and R,I are real symbols assigned to the real, imaginary communications axis.~~ Examples of complex user symbols are QPSK and OQPSK encoded data corresponding to 4-

phase and offset 4-phase symbol coding. Examples of real user symbols are PSK and DPSK encoded data corresponding to 2-phase and differential 2-phase symbol coding. Although not considered in this example, it is possible to use combinations of both complex and real data symbols.

Current real Walsh CDMA encoding for transmitter **(1)**

1 Real Walsh codes

W = Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [W(u)] matrix of row vectors W(u)

= [W(u,n)] matrix of elements W(u,n)

W(u) = Walsh code vector u for u=0,1,…,N-1

= [W(u,0), W(u,1), …, W(u,N-1)]

= 1xN row vector of chips W(u,0),….,W(u,N-1)

W(u,n) = Walsh code u chip n

= +/+1 possible values

2 Data symbols

Z(u) = Complex data symbol for user u

$R(u_R)$ = Real data symbol for user u_R assigned to the Real (inphase) axis ~~of the CDMA signal~~

$I(u_I)$ = Real data symbol for user u_I assigned to the Imaginary (quadrature) ~~axis of the CDMA signal~~

3 Walsh encoded data

Complex data symbols

Z(u,n) = Z(u) sgn{ W(u,n)}

= User u chip n Walsh encoded complex data

Real components of complex data symbols

$R(u_R,n)$ = $R(u_R)$ sgn{ $W(u_R,n)$ }

= User u_R code vector u chip n Walsh encoded

real data

$I(u_I,n) = R(u_R)\ \mathrm{sgn}\{\ W(u_R,n)\ \}$

= User u_I code vector u chip n Walsh encoded real data

where $\mathrm{sgn}\{\ (o)\ \}$ = Algeraic sign of "(o)"

u_R and u_I are encoded with the same real Walsh code vector u

4 PN scrambling by long and short PN (pseudo-noise) codes

$P_2(n)$ = Chip n of PN long code

~~$P_{R2}(n)$,~~ $P_R(n)$ = Chip n of PN short ~~codes~~ code for real axis (inphase axis)

~~$P_{I2}(n)$,~~ $P_I(n)$ = Chip n of PN short ~~codes~~ code for imaginary ~~Axis~~axis (quadrature axis)

Complex data symbols:

$Z(n)$ = PN scrambled real Walsh encoded data chips after summing over the users

$$= \sum_u \mathbf{Z(u,n)P_2}(n)\,[P_R(n) + j\,P_I(n)]$$

$$= \sum_u \mathbf{Z(u,n)}\mathrm{sign}\{P_2(n)\}\,[\mathrm{sign}\{P_R(n)\} + j\,\mathrm{sign}\{P_I(n)\}]$$

= Real Walsh CDMA encoded complex data chips

Real omponents of complex data symbols:

$Z(n)$ =

$$[\sum_{u_R}\mathbf{R(u_R,n)})+\mathbf{j}\sum_{u_I}\mathbf{I(u_I,n)}\ ]\,\mathrm{sign}\{P_2(n)\}[\mathrm{sign}\{P_R(n)\} + j\ \mathrm{sign}\{P_I(n)\}]$$

= Real Walsh CDMA encoded real data chips along inphase and quadrature axes

User data is encoded by the Walsh CDMA codes **3.** Each of the user symbols $Z(u), R(u_R), I(u_I)$ is assigned a unique real Walsh code vector. ~~$W(u), W(u_R), W(u_I)$.~~ Walsh encoding of each user

data symbol generates an N-chip sequence with each chip in the sequence consisting of the user data symbol with the sign of the corresponding Walsh code chip, which means each chip = [Data symbol] x [Sign of Walsh chip].

The Walsh encoded data symbols are summed and encoded with PN long and short spreading codes **4**. These PN long codes are real and the short codes are complex consisting of independent codes along the inphase and quadrature axes, so that the individual PN codes are 2-phase with each chip equal to +/-1 which means PN encoding consists of sign changes with each sign change corresponding to the sign of the PN chip. Encoding with PN means each chip of the summed Walsh encoded data symbols has a sign change when the corresponding PN chip is -1, and remains unchanged for +1 values. This operation is described by a multiplication of each chip of the summed Walsh encoded data symbols with the sign of the PN chip. ~~Purpose of the PN encoding for complex data symbols is to provide scrambling of the summed Walsh encoded data symbols as well as isolation between groups of users. Purpose of the separate PN encoding for the real and imaginary axes is to provide approximate orthogonality between the real and imaginary axes, since the same Walsh orthogonal codes are being used for these axes. Another PN encoding can be used as illustrated in these equations for the combined real and imaginary CDMA signals to provide scrambline and isolation between groups of users.~~

Receiver ~~equations~~ Equation **(2)** describes a representative real Walsh CDMA decoding for the receiver in FIG. **3A,3B**. The receiver front end **5** provides estimates $\{\hat{Z}(n)=\hat{R}(n)+\mathrm{j}\ \hat{I}(n)\}$ of the transmitted real Walsh CDMA encoded chips {Z(n)=R(n)+jI(n)} for the complex and real data symbols. Orthogonality property **6** is expressed as a matrix product of the real Walsh code chips or equivalently as a matrix produce of the Walsh code chip numerical

signs. The 2-phase PN codes **7** have the useful decoding property that the square of each code chip is unity which is equivalent to observing that the square of each code chip numerical sign is unity. Decoding algorithms **8** perform the inverse of the signal processing for the encoding in equations (1) to recover estimates $\{\hat{Z}(u)\}$ or $\{\hat{R}(u_R),\ \hat{I}(u_I)\}$ of the transmitter user symbols $\{Z(u)\}$ or $\{R(u_R),\ I(u_I)\}$ ~~for the respective complex or real data symbols.~~ with $Z(u)=R(u_R)+jI(u_I)$.

Current real Walsh CDMA decoding for receiver **(2)**

5 Receiver front end provides estimates $\{\hat{Z}(n) = \hat{R}(n) + j\hat{I}(n)\}$ of the encoded transmitter chip symbols $\{Z(n)=R(n)+jI(n)\}$ for the complex and real data symbols

6 Orthogonality property of real Walsh NxN matrix W

$$\sum_n W(\hat{u},n)\,W(n,u) = \sum_n \mathrm{sign}\{W(\hat{u},n)\}\,\mathrm{sign}\{W(n,u)\}$$
$$= N\ \delta(\hat{u},u)$$

where $\delta(\hat{u},u)$ = Delta function of $\hat{u}$ and u

$$= 1 \quad \text{for} \quad \hat{u} = u$$
$$= 0 \quad \text{otherwise}$$

$W' = [W(n,u)]$

= transpose of W

7 PN decoding property

for real PN long code

$P_2(n)P_2(n) = \mathrm{sgn}\{P_2(n)\ \mathrm{sgn}\{P_2(n)\}$

$= 1$

for complex PN short code

$[P_R(n) + j\ P_I(n)]\ [P_R(n) - j\ P_I(n)] = 2$

8 Decoding algorithm

Complex data symbols

$\hat{Z}(u) =$

$$N^{-1} \sum_{n} \hat{\mathbf{Z}}(\mathbf{n})[\mathrm{sign}\{P_2(n)\}\ [\mathrm{sign}\{P_R(n)\} - j\,\mathrm{sign}\{P_I(n)\}]\ \mathrm{sign}\{W(n, u)\}$$

= Receiver estimate of the transmitted complex data symbol Z(u)

Real components of complex data symbols

$\hat{R}(u_R) =$

$$\mathrm{Real}[\ N^{-1} \sum_{n} \hat{\mathbf{Z}}(\mathbf{n})\,[\mathrm{sgn}\{P_R(n)\} - j\,\mathrm{sgn}\{P_I(n)\}]\ \mathrm{sgn}\{P_2(n)\}\mathrm{sgn}\{W(n, u_R)\}\ ]$$

= Receiver estimate of the transmitted complex data symbol $R(u_R)$

$\hat{I}(u_I) =$

$$\mathrm{Imag}[\ N^{-1} \sum_{n} \hat{\mathbf{Z}}(\mathbf{n})\,[\mathrm{sgn}\{P_R(n)\} - j\,\mathrm{sgn}\{P_I(n)\}]\ \mathrm{sgn}\{P_2(n)\}\mathrm{sgn}\{W(n, u_I)\}\ ]$$

= Receiver estimate of the transmitted complex data symbol $I(u_I)$

FIG. **1A** CDMA transmitter block diagram is representative of a current CDMA transmitter which includes an implementation of the current real Walsh CDMA channelization encoding in equations **(1)**. This block diagram becomes a representative implementation of the CDMA transmitter which implements the ~~new~~ Hybrid ~~complex~~ Walsh CDMA encoding when the current real Walsh CDMA encoding **13** is replaced by the ~~new~~ Hybrid ~~complex~~ Walsh CDMA encoding of this invention. Signal processing starts with the stream of user

input data words **9**. Frame processor **10** accepts these data words and performs the encoding and frame formatting, convolutional or turbo encoded, and repeated and punctured, and passes the outputs to the symbol encoder **11** which encodes the frame symbols into amplitude and phase coded symbols **12** which could be complex {Z(u)} or real {R(u_R), I(u_I)) depending on the application. These symbols **12** are the inputs to the current real Walsh CDMA encoding in equations **(1)**. Inputs {Z(u)}, {R(u_R), I(u_I)) **12** are real Walsh encoded, summed over the users, and scrambled by the real long PN code and by the complex short PN code in the current real Walsh CDMA encoder **13** to generate the complex output chips {Z(n)} **14**. This encoding **13** is a representative implementation of equations **(1)**. These output chips Z(n) are waveform modulated **15** to generate the analog complex signal z(t) which is single sideband upconverted, amplified, and transmitted (Tx) by the analog front end of the transmitter **15** as the real waveform v(t) **16** at the carrier frequency f_0 whose amplitude is the real part of the complex envelope of the baseband waveform z(t) multiplied by the carrier frequency and the phase angle ϕ accounts for the phase change from the baseband signal to the transmitted signal.

FIG. **1B** is a representative wireless cellular communication network application of the generalized CDMA trasmitter in FIG. **1A**. FIG. **1B** is a schematic layout of part of a CDMA network which depicts cells **101,102,103,104** that partition this portion of the area coverage of the network, depicts one of the users **105** located within a cell with forward and reverse communications links **106** with the cell-site base station **107**, depicts the base station communication links **108** with the MSC/WSC **109**, and depicts the MSC/WSC communication links with another base station **117**, with another MSC/WSC **116**, and with external elements **110,111,112,113,114,115**. One or more base stations are assigned to each cell or multiple cells or sectors of cells depending on

the application. One of the base stations **109** in the network serves as the MSC (mobile switching center) or WSC (wireless switching center) which is the network system controller and switching and routing center that controls all of user timing, synchronization, and traffic in the network and with all external interfaces including other MSC's. External interfaces could include satellite **110,** PSTN (public switched telephone network) **111,** LAN (local area network) **112,** PAN (personal area network) **113,** UWB (ultra-wideband network) **114,** and optical networks **115.** As illustrated in the figure, base station **107** is the nominal cell-site station for cells i-2, i-1, i, i+1 identified as **101,102,102,104,** which means it is intended to service these cells with overlapping coverage from other base stations. The cell topology and coverage depicted in the figure are intended to be illustrative and the actual cells could be overlapping and of differing shapes. Cells can be sub-divided into sectors. Not shown are possible subdivision of the cells into sectors and/or combining the cells into sectors. Each user in a cell or sector communicates with a base station which should be the one with the strongest signal and with available capacity. When mobile users cross over to other cells and/or are near the cell boundary a soft handover scheme is employed for CDMA in which a new cell-site base station is assigned to the user while the old cell-site base station continues to service the user for as long as required by the signal strength.

Fig. **1C** depicts a representative embodiment of the CDMA transmitter signal processing in **13,15** of FIG. **1A** for the forward and reverse CDMA links **106** in FIG. **1B** between the base station and the users for CDMA2000 and W-CDMA that implements the CDMA coding for synchronization, real Walsh channelization, and scrambling of the data for transmission. Depicted are the principal signal processing from **13,15** in FIG. **1A** that is relevant to this invention disclosure. CDMA2000 and W-CDMA use real Walsh codes **120** for channelization of the data expressed in

layered format which progresses from the highest data rate for the shortest codes to the lowest data rate for the longest codes in a format referred to as OVSF (orthogonal fixed spreading factor) codes. This OVSF implementation of real Walsh codes **120** supports a variable data rate with variable length real Walsh codes over a fixed transmission channel. Long codes **also 22** are PN code sequences intended to provide separation of the cells and sectors and to provide protection against multipath. Long PN codes **122** for IST-95/IST-95A use code segments from a 42 bit maximal-length shift register code with code length (2^42-1). The separation between code segments is sufficient to make them statistically independent. These codes can be converted to complex codes by using the code for the real axis and a delayed version of the code for the quadrature axis. Different code segments are assigned to different cells or sectors to provide statistical independence between the communications links in different cells or sectors. Short PN codes **124,125** are used for scrambling and synchronization of CDMA code chips from the real Walsh encoding of the data symbols after they are multiplied by a long code. These codes include real and complex valued segments of maximal-length shift register sequences and segments of complex Gold codes which range in length from 256 to 38,400 chips and also are used for user separation and sector separation within a cell.

FIG. **1C** data inputs **112** in FIG. **1A** to the transmitter CDMA signal processing are the inphase data symbols $R(u_R)$ **118** and quadrature data symbols $I(u_I)$ **119** of the complex data symbols $Z(u)=R(u_R)+j\ I(u_I)$ from the block interleaving processing in the transmitter in **12** in FIG. **1A**. As described previously in Equation **(1)** in greater detail, a real Walsh code **120** ranging in length from N=4 to N=512 chips spreads and channelizes the data by encoding **121** the inphase and quadrature data symbols with rate R=N codes corresponding to the channel assignments of the data chips. A long PN code **122** encodes the inphase and quadrature real

Walsh encoded chips **123** with a 0,1 binary code which is generated from segments of a maximal-length 42 bit shift register code for IS-95/IS-95A and an equivalent PN code for CDMA2000 and W-CDMA. Encoding is a (+/-) sign change to the chip symbols corresponding to the 0,1 code value. Long code characteristics have the PN property with quasi-orthogonal auto-correlations and cross-correlations. The long PN code **122** can be easily converted to a complex code using different code phases and families or code segments for the inphase and quadrature axes and which means in **4** $P_2(n)$ becomes complex in Equation **(1)** whereupon the encoding **123** is replaced by a complex multiply operation similar to the short code complex multiply **126** and in **4** in Equation **(1)**. This long PN code covering of the real Walsh encoded chips is followed by a short complex PN code covering in **124,125,126**. Short PN codes include complex Gold code segments and complex complex valued segments from maximal-length shift register codes, as well as Kasami sequen**ces**, Kerdock codes, and Golay sequences. As described in **4** in Equation **(1)** the complex PN short code is an inphase short code **124** and a quadrature short code **125** which are statistically independent and quasi-orthogonal. This complex PN short code encodes the inphase and quadrature chips with a complex multiply operation **126** as described in **4** in Equation **(1)**. Outputs are inphase and quadrature components of the complex chips which have been rate R=1 phase coded with both the long and short PN codes. Low pass filtering (LPF), summation (Σ) over the Walsh channels for each chip symbol, modulation of the chip symbols to generate a digital waveform, and digital-to-analog (D/A) conversion operations **127** are performed on these encoded inphase and quadrature chip symbols to generate the analog inphase x(t) signal **128** and the quadrature y(t) signal **129** which are the components of the complex signal z(t)=x(t)+jy(t) where $j=\sqrt{-1}$. This complex signal z(t) is single-sideband up-converted to an IF frequency and then up-converted by the RF frequency front end to the RF signal v(t) **133** which is defined in **16** in

FIG. **1A**. Single sideband up-conversion of the baseband signal is performed by multiplication of the inphase signal x(t) with the cosine of the carrier frequency f_0 **130** and the quadrature signal y(t) by the sine of the carrier frequency **131** which is a 90 degree phase shifted version of the carrier frequency, and summing **132** to generate the real signal v(t) **133**.

FIG. **1C** depicts an embodiment of the current CDMA transmitter art and with current art signal processing changes this figure is representative of other current art CDMA transmitter embodiments for this invention disclosure. Other embodiments of the CDMA transmitter include changes in the ordering of the signal processing, single channel versus multi-channel real Walsh encoding, summation or combining of the Walsh channels by summation over like chip symbols, analog versus digital signal representation, baseband versus IF frequency CDMA processing, the order and placement in the signal processing thread of the Σ, LPF, and D/A signal processing operations, and the up-conversion processing. The order of the rate R=1 PN multiplies in FIG. **1C** can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short PN code complex multiply **124,125,126** in FIG. **1C** can occur prior to the long PN code multiply **122,123** and moreover the long PN code can be complex with the real multiply **123** replaced by the equivalent complex multiply **126**.

It should be obvious to anyone skilled in the communications art that this example implementation in FIG. **1A,1B,1C** clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. **2** real Walsh CDMA encoding is a representative implementation of the real Walsh CDMA encoding **13** in FIG. **1A** and **120,121** in FIG. **1C** and in equations **(1)**. Inputs are the user data symbols which could be complex $\{Z(u)\}$ or real $(\{R(u_R)\},+j\{I(u_I)\})$ **17**. For complex and real data symbols the encoding of each user by the corresponding Walsh code is described in **18** by the implementation of transferring the sign of each Walsh code chip to the user data symbol followed by a 1-to-N expander $1\uparrow N$ (which is rate R=N encoding) of each data symbol into an N chip sequence using the sign transfer of the Walsh chips.

For complex data symbols $\{Z(u)\}$ the sign-expander operation **18** generates the N-chip sequence $Z(u,n) = Z(u)—\mathrm{sgn}\{W(u,n)\}—= Z(u)—W(u,n)$ for $n=0,1,\ldots,N-1$ for each user $u=0,1,\ldots,N-1$. This Walsh encoding serves to spread each user data symbol into an orthogonally encoded chip sequence which is spread over the CDMA communications frequency band. The Walsh encoded chip sequences for each of the user data symbols are summed over the users **19** followed by PN encoding with the scrambling sequences $P_2(n)[P_R(n)+jP_I(n)]$ **21**. PN encoding is implemented by transferring the sign of each PN chip to the summed chip of the Walsh encoded data symbols. Output is the stream of complex CDMA encoded chips $\{Z(n)\}$ **22**. The switch **20** selects the appropriate signal processing path for the complex and real data symbols.

For real data symbols $\{R(u_R)+jI(u_I)\}$ the real and imaginary communications axis data symbols are separately Walsh encoded **18**, summed **19**, and then PN encoded **19** to provide orthogonality between the channels along the real and imaginary communications axes. Output is complex combined **19** and PN encoded with the scrambling sequence $P_2(n)[P_R(n)+ jP_I(n)]$ **21**. Output is the stream of complex CDMA encoded chips $\{Z(n)\}$ **22**.

It should be obvious to anyone skilled in the communications art that this example implementation in FIG. **2** clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. **3A** CDMA receiver block diagram is representative of a current CDMA receiver which includes an implementation of the current real Walsh CDMA decoding in equations **(2)**. This block diagram becomes a representative implementation of the CDMA receiver which implements the ~~new~~ Hybrid ~~complex~~ Walsh CDMA decoding when the current real Walsh CDMA decoding **27** is replaced by the new ~~complex~~ Hybrid Walsh CDMA decoding of this invention. FIG. **3A** signal processing starts with the user transmitted wavefronts incident at the receiver antenna **23** for the n_u users $u = 1, \ldots, n_u \leq N_c$. These wavefronts are combined by addition in the antenna to form the receive (Rx) signal $\hat{v}(t)$ at the antenna output **23** where $\hat{v}(t)$ is an estimate of the transmitted signal v(t) **16** in FIG. **1A**, that is received with errors in time Δt, frequency Δf, phase $\Delta\theta$, and with an estimate $\hat{z}(t)$ of the transmitted complex baseband signal z(t) **16** in FIG. **1A**. This received signal $\hat{v}(t)$ is amplified and downconverted by the analog front end **24** and then synchronized and analog-to-digital (ADC) converted **25**. Outputs from the ADC are filtered and chip detected **26** by the fullband chip detector, to recover estimates $\{\hat{Z}(n) = \hat{R}(n) + j\,\hat{I}(n)\}$ **28** of the transmitted signal which is the stream of complex CDMA encoded chips {Z(n)=R(n)+jI(n)} **14** in FIG. **1A** for both complex and real data symbols. The CDMA decoder **27** implements the algorithms in equations **(2)** by stripping off the PN code(s) and decoding the received CDMA real Walsh orthogonally encoded chips to recover estimates $\{\hat{Z}(u) = \hat{R}(u_R) + \mathrm{j}\,\hat{I}(u_I)\}$ **29** of the transmitted user data symbols

$\{Z(u)= R(u_R) + jI(u_I)\}$ **12** in FIG. **1A**. Notation introduced in FIG. **1A** and 3A assumes that the user index $u=u_R=u_I$ for complex data symbols, and for real data symbols the user index u is used for counting the user pairs (u_R, u_I) of real and complex data symbols. These estimates are processed by the symbol decoder **30** and the frame processor **31** to recover estimates **32** of the transmitted user data words.

Fig. **3B** depicts a representative embodiment of the receiver signal processing **27** in FIG. **3A** for the forward and reverse CDMA links **106** in FIG. **1B** between the base station and the user for CDMA2000 and W-CDMA that implements the CDMA decoding for the long and short codes, the real Walsh codes, and for recovering estimates $\hat{R}$, $\hat{I}$ **148,149** of the transmitted inphase and quadrature data symbols R **118** and I **119** in FIG. **1C**. Depicted are the principal signal processing that is relevant to this invention disclosure. Signal input $\hat{v}(t)$ **134** in FIG. **3B** is the received transmitted CDMA signal v(t) **16** in FIG. **1A** and **133** in FIG. **1C**. The signal is handed over to the inphase mixer which multiplies $\hat{v}(t)$ by the cosine **135** of the carrier frequency f_0 followed by a low pass filtering (LPF) **137** which removes the mixing harmonics, and to the quadrature mixer which multiplies $\hat{v}(t)$ by the sine **136** of the carrier frequency f_0 followed by the LPF **137** to remove the mixing harmonics. These inphase and quadrature mixers followed by the LPF perform a Hilbert transform on v(t) to down-convert the signal at frequency f_0 and to recover estimates $\hat{x}$, $\hat{y}$ of the inphase component and the quadrature component of the transmitted complex baseband CDMA signal $z(t)=x(t)+jy(t)$ in **128,129** FIG. **1C** The $\hat{x}(t)$ and $\hat{y}(t)$ baseband signals are analog-to-digital (D/A) **140** converted and demodulated (demod.) to recover the transmitted inphase and quadrature baseband chip symbols. The complex short PN code cover is removed by a complex multiply **143** with the complex conjugate of the short PN

code implemented by using the inphase short code **141** and the negative of the quadrature short code **142** in the complex multiply operation **143**. The long PN code cover is removed by a real multiply **145** with the long code **144** implemented as (+/-) sign changes to the chip symbols since this is a binary 0,1 code. The decovered chip symbols are rate R=1/N decoded by the real Walsh decoders **146** using the real Walsh code **147** which implement the real Walsh decoding **36** in FIG. **4**. Decoded output symbols are the estimates $\hat{R}$, $\hat{I}$ **148,149**—of the inphase data symbols R and the quadrature data symbols I from the transmitters in **12** FIG. **1A** and **118,119** FIG.**1C**.

FIG. **3B** depicts an embodiment of the current CDMA receiver art and with current art signal processing changes this figure is representative of other current art CDMA receiver embodiments for this invention disclosure. Other embodiments of the CDMA receiver include changes in the ordering of the signal processing, analog versus digital signal representation, down-conversion processing, baseband versus IF frequenncy CDMA processing, order and placement in the signal processing thread of the Σ, LPF, and A/D signal processing operations, and single channel versus multi-channel real Walsh decoding. Code decovering is implemented as rate R=1 code multiply operations which implement the phase subtraction of the code symbols from the chip symbols. The order of the rate R=N code multiplies in FIG. **3** can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **141,142,143** in FIG. **3B** can occur prior to the long code multiply **144,145** and moreover the long code can be complex with the real multiply **145** replaced by the equivalent complex multiply **143**.

It should be obvious to anyone skilled in the communications art that this example implementation clearly defines the fundamental current CDMA signal processing relevant

to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. **4** real Walsh CDMA decoding is a representative implementation of the real Walsh CDMA decoding **27** in FIG. **3A, 144,145** in FIG. **3B,** and in equations **(2)**. Inputs are the received estimates of the complex CDMA encoded chips $\{\hat{Z}(n)\}$ **33**. The PN scrambling code is stripped off from these chips **34** by changing the sign of each chip according to the numerical sign of the real and imaginary components of the complex conjugate of the PN code as per the decoding algorithms **8** in equations **(2)**.

For complex data symbols **35** the real Walsh channelization coding is removed by a pulse compression operation consisting of multiplying each received chip by the numerical sign of the corresponding Walsh chip for the user and summing the products over the N Walsh chips **36** to recover estimates $\{\hat{Z}(u)\}$ of the user complex data symbols $\{Z(u)\}$. The switch **35** selects the appropriate signal processing path for the complex and real data symbols.

For real data symbols **35** the next signal processing operation is the removal of the PN codes from the real and imaginary axes. This is followed by stripping off the real Walsh channelization coding by multiplying each received chip by the numerical sign of the corresponding Walsh chip for the user and summing the products over the N Walsh chips **36** to recover estimates $\{\hat{R}(u_R), \hat{I}(u_I)\}$ of the user real data symbols $\{R(u_R), I(u_I)\}$.

It should be obvious to anyone skilled in the communications art that this example implementation clearly defines the fundamental current CDMA signal processing relevant

to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

For cellular applications the transmitter description describes the transmission signal processing applicable to this invention for both the hub and user terminals, and the receiver describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.

Complex Walsh codes have been proposed during the early work on Walsh bases and codes, based on the even and odd sequency property of the Walsh bases and their correspondence with the even cosine real components and odd sine imaginary components of the DFT (Discrete Fourier Transform). Sequency for the Walsh is the average rate of phase rotations and is the Walsh equivalent of the frequency rotation for the Fourier and DFT bases. Walsh bases are re-ordered Hadamard bases where the ordering corresponds to increasing sequency. Gibbs in the 1970 report "Discrete Complex Walsh Sequences" developes a complex Walsh basis (each basis vector is a complex orthogonal CDMA code) from the real Walsh with the property that similar to the DFT the real part is an even function and the imaginary part is an odd function and takes the values {1,j,-1,-j} where j=√(-1). Ohnsorg et. al. in the 1970 report "Application of Walsh Functions to Complex Signals" developed a complex Walsh basis from the real Walsh by generating a complex binary matrix from the Hadamard representation with values {1,j.-1.j} and combining the scaled sum and differences of this matrix to form a complex Walsh matrix of basic vectors which gives this matrix the real even and imaginary odd properties of the DFT. These complex Walsh bases have had no apparent value in signal processing since they were not derived as an isomorphic mapping from the DFT and therefore do not exhibit any of the DFT performance advantages over the real Walsh and moreover do not have simple and fast algorithms

for coding and decoding and as a result they have not been used for CDMA communications.

Golay-Hadamard sequences have been developed for CDMA which can be generated as complex sequences with values {1,j,-1,-j} and with a quasi-orthogonality property between basis vectors or codes. "Golay Sequences for DS (direct sequence) CDMA Applications" by Seberry et. al. and posted on the internet develops the sequences and correlation properties. These sequences are used to reduce the autocorrelation and cross-correlation sidelobes of the Hadamard and Walsh codes. Given a NxN Hadamard matrix H or equivalently an NxN Walsh matrix W, an NxN diagonal matrix D can be constructed whose diagonal elements are a 2-phase (bipolar) or a 4-phase (quadri-phase) Golay sequence of length N. For W the corresponding diagonal matrix is D which is a diagonal matrix of the same size as W and with diagonal elements consisting of a Golay sequence. With the proper selection of the Golay sequence, the sets of codes H*D and W*D codes have lower autocorrelation and cross-correlation sidelobes than the H,W respectively. It is observed that the autocorrelation and cross-correlation sidelobes are comparable to those obtained using a real and complex PN overlays of the H,W.

Yang (US 6,674,712) combines the quaternary complex-valued Kerdock codes with the real Walsh codes to generate a set of quasi-orthogonal CDMA codes using the complex multiply operation **126** in FIG. **1C** to combine the real Walsh codes **120, 121** with the complex Kerdock codes upon replacing the complex short PN codes **124, 125** with the Kerdock codes, adding a zero to the Kerdock codes of length (2^K-1) to make them 2^M chip codes and using real Walsh 2^M chip codes to allow the phase addition of these codes in the complex multiply **126**. Prior art represented by the paper by Hannon et. al. (IEEE Trans. Inform. Theory, vol. 40, pp. 301-319, 1994) and other prior publications derived the Kerdock

codes with the permutation and construction algorithm in this patent. Unlike Yang, current CDMA art uses the same 2^M PN code for all real Walsh channelization codes which keeps the orthogonality property while providing the desired low correlation sidelobe properties.

Li (US 6,389,138) uses the (2^42-1) bit long code generator output for the inphase component and a delayed output for the quadrature component to generate a complex long code for CDMA applications. This innovation applies a code principle previously used in IS-95A,B which observes that segments of code from a maximal-length shift register code generator are statistically independent when the segments are sufficiently separated. Real Walsh codes **120** in FIG. **1C** are used for channelization codes for user traffic and communications housekeeping functions that include pilot signals, control channels, supplemental channels, reverse channels, for both inphase and quadrature components of the complex signal **121**. With Li's invention the real Walsh inphase and quadrature encoded signals **121** are complex encoded with Li's complex long code as described in FIG. **1C** upon replacing the long PN code with Li's code and the real multiply **123** with the complex multiply **126**.

Prior art in the vol. 27 November 1973 Archive fur Elektronik und Uebertragungsteckhik paper "Aufbau und Eigenschaften von quasiothogonalen Codekollektiven" and in the 1981 Lincoln Lab. report IFF-7 introduced the concept of covering the real Walsh encoded data with a real PN code in order to improve the correlation performance with time and frequency offsets. This concept was introduced well in advance of it's use in the late 1980's introduction of CDMA (US 5,103,459) wherein the real Walsh encoded data is covered by a real PN code and which covering was later updated using a complex PN code depicted in **24,25,26** FIG. **2** and decovered in **41,42,43** FIG.**3**.

SUMMARY OF THE INVENTION

~~**SUMMARY OF INVENTION**~~

The present invention provides a method and system for the generation and encoding and fast decoding of Hybrid Walsh orthogonal codes for use in CDMA communications as the orthogonal channelization codes to replace the real Walsh codes. Hybrid Walsh codes are complex Walsh codes that have an isomorphic one-to-one correspondence with the DFT (discrete Fourier transform) codes. Additionally, the encoding (covering) of the Hybrid Walsh complex code by a complex PN code is a novel idea introduced in this invention disclosure.

Hybrid Walsh codes are the closest possible approximation to the DFT with orthogonal code vectors taking the values {1+j, -1+j, -1-j, 1-j} or equivalently the values {1, j, -1, -j} when the axes are rotated and renormalized where $j=\sqrt{-1}$ and Hybrid Walsh codes offer performance improvements over real Walsh codes for CDMA communications. Hybrid Walsh codes are derived by separate lexicographic reordering permutations of real Walsh codes for the inphase (real) components and for the quadrature (imaginary) components and have simple implementations and fast encoding and decoding algorithms, where the lexicographic rule is to order the code vectors with increasing sequency. Suppression of the quadrature code components of the Hybrid Walsh codes gives the real Walsh codes along the inphase axis and suppression of the inphase code components of the Hybrid Walsh codes gives the real Walsh codes along the quadrature axis.

The invention discloses a means for the Hybrid Walsh encoder and decoder to be generalized by combining with DFT, Hadamard, and other codes using tensor product construction, direct sum construction, and functional combining. This

construction increases the choices for the code length by allowing the combined use of Hybrid Walsh with lengths 2^M and 4t where M and t are integers, with DFT complex orthogonal codes with lengths N where N is an integer, with Hadamard codes, and with quasi-orthogonal PN families of codes including segments of maximal-length shift register codes, Gold, Kasami, Golay, Kerdock, Preparate, Goethals, STC, and with other families of codes.

~~This invention is a new approach to the application of Walsh orthogonal codes for CDMA, which replaces the current real Walsh codes with the new complex Walsh codes and the hybrid complex Walsh codes disclosed in this invention. Real Walsh codes are used for current CDMA applications and will be used for all of the future CDMA systems. This invention of complex Walsh codes will provide the choice of using the new complex Walsh codes or the real Walsh codes since the real Walsh codes are the real components of the complex Walsh codes. This means an application capable of using the complex Walsh codes can simply turn-off the complex axis components of the complex Walsh codes for real Walsh CDMA coding and decoding.~~

~~The complex Walsh codes of this invention are proven to be the natural development for the Walsh codes and therefore are the correct complex Walsh codes to within arbitrary factors that include scale and rotation, which are not relevant to performance. This natural development of the complex Walsh codes in the N-dimensional complex code space~~ $\cancel{C^N}$ ~~extended the correspondences between the real Walsh codes and the Fourier codes in the N-dimensional real code space~~ $\cancel{R^N}$~~, to correspondences between the complex Walsh codes and the discrete Fourier transform (DFT) codes in~~ $\cancel{C^N}$~~.~~

~~The new 4-phase complex Walsh orthogonal CDMA codes provide fundamental performance improvements compared to the 2-phase real Walsh codes which include an increase in the carrier-to-noise ratio (CNR) for data symbol recovery in the receiver, lower~~

~~correlation side-lobes under timing offsets both with and without PN spreading, lower levels of harmonic interference caused by non-linear amplification of multi-carrier CDMA signals, and reduced phase tracking jitter for code tracking to support both acquisition and synchronization. These potential performace improvements simply reflect the widely known principle that complex CDMA is better than real CDMA.~~

~~The new hybrid complex Walsh orthogonal CDMA codes increase the choices for the code length by allowing the combined use of complex Walsh and discrete Fourier transform complex orthogonal codes using a Kronecker cconstruction, direct sum constructioin, as well as the possibility for more general functional combining.~~

~~**BRIEF DESCRIPTION OF DRAWINGS AND PERFORMACE DATA**~~

BRIEF DESCRIPTION OF THE DRAWINGS AND THE PERFORMANCE DATA

The above-mentioned and other features, objects, design algorithms, implementations, and performance advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings and performance data wherein like reference characters and numerals denote like elements, and in which:

FIG. **1A** is a representative CDMA transmitter signal processing implementation block diagram~~,~~ with emphasis on the current real Walsh CDMA encoding and which contains the signal processing elements addressed by this invention disclosure.

FIG. **1B** is a schematic CDMA cellular network with the communications link between a base station and a user.

FIG. **1C** depicts the transmit CDMA encoding signal processing implementation for the forward and reverse links

between the base station and one of the users in the cellular network.

FIG. **2** is a representative CDMA encoding signal processing implementation diagram~~,~~ with emphasis on the current real Walsh CDMA encoding and which contains the signal processing elements addressed by this invention disclosure.

FIG.~~3~~ **3A** is a representative CDMA receiver signal processing implementation block diagram~~,~~ with emphasis on the current real Walsh CDMA decoding and which contains the signal processing elements addressed by this invention disclosure.

FIG. **3B** depicts the receive CDMA decoding signal processing implementation for the forward and reverse links between the base station and one of the users in the cellular network.

FIG. **4** is a representative CDMA decoding signal processing implementation diagram~~,~~ with emphasis on the current real Walsh CDMA decoding and which contains the signal processing elements addressed by this invention disclosure.

FIG. **5** is a representative correlation plot of the correlation between the complex discrete Fourier transform (DFT) cosine and sine code ~~component~~ vectors and the real Fourier transform cosine and sine code ~~component~~ vectors.

FIG. **6A** is a representative CDMA encoding signal processing implementation diagram~~,~~ with emphasis on the ~~new complex~~Hybrid Walsh CDMA encoding which contains the signal processing elements addressed by this invention disclosure

FIG. **6B** defines the implementation algorithm of this invention disclosure for generating Hybrid Walsh codes from real Walsh.

FIG. **6C** defines the implementation algorithm of this invention disclosure for generating Hybrid Walsh codes from the even and odd real Walsh codes.

FIG. **6D** is an embodiment of this invention disclosure for the transmit CDMA encoding signal processing implementation for the cellular network using Hybrid Walsh codes in place of real Walsh codes for the forward and reverse links between the base station and user.

FIG. **7A** is a representative CDMA decoding signal processing implementation diagram~~,~~ with emphasis on the ~~new complex~~ Hybrid Walsh CDMA decoding and which contains the signal processing elements addressed by this invention disclosure.

FIG. **7B** is an embodimentof of this invention disclosure for the receive CDMA decoding signal processing for the cellular network using Hybrid Walsh codes in place of real Walsh codes for the forward and reverse links between the base station and user.

~~**DISCLOSURE OF INVENTION**~~

DISCLOSURE OF THE INVENTION

~~Real orthogonal CDMA code space R^N for Hadamard, Walsh, and Fourier codes:~~

The ~~new complex~~ Hybrid Walsh complex–orthogonal CDMA codes are derived from the current real Walsh codes by starting with the correspondence of the current real Walsh codes with the

discrete Fourier transform (DFT) basis vectors. Consider the real orthogonal CDMA code space R^N consisting of N-orthogonal real code vectors. Examples of code sets in R^N include the Hadamard, Walsh, and Fourier. The corresponding matrices of code vectors are designated as H, W, F respectively and as defined in equation~~s~~ **(~~1~~3)** respectively consist of N-rows of N-chip code vectors. Hadamard codes in their reordered form known as Walsh codes are used in the current CDMA, in the ~~proposals for the next generation~~ G3 CDMA, and in the proposals for all future CDMA. Walsh codes reorder the Hadamard codes according to increasing sequency~~. These codes assumed +/-1 values. Sequency~~ which is the average rate of change of the sign of the codes. ~~and the reordering places the Walsh codes in correspondence to the DFT wherein sequency is in correspondence with frequency in the DFT.~~

~~It is important to note that the correspondence "sequency-frequency" only applies to the complex DFT matrix E consisting of the N-row vectors {E(u)= [E(u,0),…,E(u,N-1)] wherein the elements of E are~~ $\cancel{E(u,n)=e^{j(2\pi\ un/N)},\ u,n = 0,1,\ldots,N-1\}.}$ ~~Historically it has not been applied to the Fourier basis F in~~ $\cancel{R^N.}$

~~Equations **(1)** define the three sets H,W,F of real orthogonal codes in~~ $\cancel{R^N}$ ~~with the understanding that the H and W are identical except for the ordering of the code vectors.~~ Hadamard **37** and Walsh **38** ~~orthogonal functions are basis vectors in~~ $\cancel{R^N}$ ~~and~~ are used as code vectors for orthogonal CDMA channelization coding. Hadamard **37** and Walsh **38** equations of definition are widely known. ~~with examples given in Reference [6].~~ Likewise, the Fourier **39** equations of definition are widely known within the engineering and scientific communities, wherein

N-chip real orthogonal CDMA codes **(3)**

37 Hadamard codes

H = Hadamard NxN orthogonal code matrix consisting of

N rows of N chip code vectors

= [H(u)] matrix of row vectors H(u)

= [H(u,n)] matrix of elements H(u,n)

H(u) = Hadamard code vector u

= [H(u,0), H(u,1), …, H(u,N-1)]

= 1xN row vector of chips H(u,0),….,H(u,N-1)

H(u,n) = Hadamard code u chip n

= +/+1 possible values

$= (-1)\wedge [\sum_{i=0}^{i=M-1} u_i n_i]$

where $u = \sum_{i=0}^{i=M-1} u_i 2^i$ binary representation of u

$n = \sum_{i=0}^{i=M-1} n_i 2^i$ binary representation of n

38 Walsh codes

W = Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [W(u)] matrix of row vectors W(u)

= [W(u,n)] matrix of elements W(u,n)

W(u) =Walsh code vector u

= [W(u,0), W(u,1), …, W(u,N-1)]

W(u,n) = Walsh code u chip n

= +/+1 possible values

$= (-1)\wedge [u_{M-1} n_0 + \sum_{i=1}^{i=M-1} (u_{M-1-i} + u_{M-i}) n_i]$

39 Fourier codes

F = Fourier NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [F(u)] matrix of row vectors F(u)

$= \left[\frac{C}{S}\right]$

C = N/2+1 x N matrix of row vectors C(u)

$C(u)$ = Even code vectors for $u=0,1,\ldots,N/2$

$= [1, \cos(2\pi\ u1/N),\ldots,\cos(2\pi\ u(N-1/N)]$

S = $N/2-1 \times N$ matrix of row vectors $S(u)$

$S(\Delta u)$ = Odd code vectors for $u=N/2+\Delta u$, $\Delta u=1,2,\ldots,N/2-1$

$= [\sin(2\pi\ \Delta u\ 1/N),\ldots,\sin(2\pi\ \Delta u(N-1)/N)]$

where $F(u) = C(u)$ for $u=0,1,\ldots,N/2$

$= S(\Delta u)$ for $\Delta u = u-N/2$, $u=N/2+1,\ldots,N-1$

and the cosine $C(u)$ and sine $S(\Delta u)$ code vectors are the code vectors of the Fourier code matrix F.

~~Complex orthogonal CDMA code space C^N for DFT codes:~~

The DFT (discrete Fourier transform) orthogonal codes are a complex basis for the complex N-dimensional CDMA code space C^N and consist of the DFT harmonic code vectors arranged in increasing order of frequency. Equations (4) are the definition of the DFT code vectors. The DFT definition **40** in equation **(4)** is widely known within the engineering and scientific communities. Even and odd components of the DFT code vectors **41** in equation **(4)** are the real cosine code vectors {C(u)} and the imaginary sine code vectors (S(u)} where even and odd are referenced to the midpoint of the code vectors. These cosine and sine code vectors in C^N are the extended set 2N of the ~~N~~ Fourier cosine and sine code vectors~~.~~ in R^N.

N-chip DFT complex orthogonal CDMA codes **(4)**

40 DFT code vectors

E = DFT NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [E(u)] matrix of row vectors E(u)

= [E(u,n)] matrix of elements E(u,n)

$E(u)$ = DFT code vector u

= [$E(u,0)$, $E(u,1)$, …, $E(u,N-1)$]

= 1xN row vector of chips $E(u,0),\ldots,E(u,N-1)$

$E(u,n)$ = DFT code u chip n

$= e^{j2\pi\, un/N}$

$= \cos(2\pi\, un/N) + j\sin(2\pi\, un/N)$

= N possible values on the unit circle

41 Even and odd code vectors are the extended set of Fourier even and odd code vectors in **39** equations (3_)

$C(u)$ = Even code vectors for $u=0,1,\ldots,N-1$

$= [1, \cos(2\pi\, u\, 1/N),\ldots,\cos(2\pi\, u\, (N-1)/N)]$

$S(u)$ = Odd code vectors for $u=0,1,\ldots,N-1$

$= [0, \sin(2\pi\, u\, 1/N),\ldots,\sin(2\pi\, u\, (N-1)/N)]$

$E(u) = C(u) + j\, S(u)$ for $u=0,1,\ldots,N-1$

1. Hybrid Walsh Implementation Algorithm

~~Complex orthogonal CDMA code space C^N for complex Walsh codes:~~ Step 1 in the derivation of the implementation algorithm for the ~~complex~~ Hybrid Walsh codes in this invention establishes the correspondence of the even and odd Walsh codes with the even and odd Fourier codes. Even and odd for these codes are with respect to the midpoint of the row vectors similar to the definition for the DFT vector codes **41** in equations **(4)**. Equations **(5)** identify the even and odd Walsh codes in the W basis in R^N. These even and odd Walsh codes can be placed in

Even and odd Walsh codes in R^N **(5)**

$$W_e(u) = \text{Even Walsh code vector}$$
$$= W(2u) \quad \text{for } u=0,1,\ldots,N/2-1$$
$$W_o(u) = \text{Odd Walsh code vectors}$$
$$= W(2u-1) \quad \text{for } u=1,\ldots,N/2$$

direct correspondence with the Fourier code vectors **39** in equations **(3)** using the DFT equations **(4)**. This correspondence is defined in equations **(6)** where the correspondence operator "~" represents the even and odd correspondence between the Walsh and Fourier codes, and additionally represents the sequency~frequency corresponcence.

Correspondence between Walsh and Fourier codes **(6)**

$$W(0) \sim C(0)$$
$$W_e(u) \sim C(u) \quad \text{for } u=1,\ldots,N/2-1$$
$$W_o(u) \sim S(u) \quad \text{for } u=1,\ldots,N/2-1$$
$$W(N-1) \sim C(N/2)$$

Step 2 <u>in the derivation of the implementation algorithm for the Hybrid Walsh codes</u> derives the set of N complex DFT vector codes in C^N from the set of N real Fourier vector codes in R^N. This means that the set of 2N cosine and sine code vectors in **41** in equations **(4)** for the DFT codes in C^N will be derived from the set of N cosine and sine code vectors in **39** in equations **(3)** for the Fourier codes in R^N. The first N/2+1 code vectors of the DFT basis can be written in terms of the Fourier code vectors in equations **(7)**.

DFT code vectors 0,1,…,N/2 derived from Fourier **(7)**

42 Fourier code vectors from **39** in equations **(3)** are

$C(u)$ = Even code vectors for $u=0,1,\dots,N/2$

$= [1, \cos(2\pi\ u1/N),\dots,\cos(2\pi\ u(N-1/N)]$

$S(u)$ = Odd code vectors for $u=1,2,\dots,N/2-1$

$= [\sin(2\pi\ u1/N),\dots,\sin(2\pi\ u(N-1)/N)]$

43 DFT code vectors in **41** of equations (4) are written as functions of the Fourier code vectors

$E(u)$ = DFT complex code vectors for $u=0,1,\dots,N/2$

$= C(0)$

$= C(u)+jS(u)$ for $u=1,\dots,N/2-1$

$= C(N/2)$ for $u=N/2$

The remaining set of $N/2+1,\dots,N-1$ DFT code vectors in C^N can be derived from the original set of Fourier code vectors by a correlation which establishes the mapping of the DFT codes onto the Fourier codes. We derive this mapping by correlating the real and imaginary components of the DFT code vectors with the corresponding even and odd components of the Fourier code vectors. The correlation operation is defined in equations **(8)**:

Correlation of DFT and Fourier code vectors **(8)**

Corr(even) = $C\underline{*}-\mathrm{Real}\{E'\}$

= Correlation matrix

= Matrix product of C and the real part of E conjugate transpose

Corr(odd) = $S\underline{*}-\mathrm{Imag}\{E'\}$

= Correlation matrix

= Matrix product of S and the imaginary part of E conjugate transpose

where "*" is a matrix multiply operation. The correlation peaks of these correlation matrices ~~and the results of the correlation calculations~~ are plotted in FIG.**5** for N=32 for the real cosine and the odd sine Fourier code vectors. Plotted are the correlation peaks of the 2N DFT cosine and sine codes against the N Fourier cosine and sine codes which range from −15 to +16 where the negative indices of the codes represent a negative correlation value. ~~The plotted curves are the correlation peaks.~~ These correlation curves ~~in FIG. 5~~ prove that the remaining N/2+1,…,N-1 code vectors of the DFT are derived from the Fourier code vectors by equations **(9)**

DFT code vectors N/2+1,…, N-1 derived from Fourier **(9)**

$$E(u) = C(N/2-\Delta u) - jS(N/2-\Delta u)$$
$$\text{for} \quad u = N/2 + \Delta u$$
$$\Delta u = 1,\ldots,N/2-1$$

This construction of the remaining DFT basis in equations **(9)** is an application of the DFT spectral foldover property which observes the DFT harmonic vectors for frequencies $fNT=N/2+\Delta i$ above the Nyquist sampling rate $fNT=N/2$ simply foldover such that the DFT harmonic vector for $fNT = N/2+\Delta i$ is the DFT basis vector for $fNT = N/2-\Delta i$ to within a fixed sign and fixed phase angle of rotation.

Step 3 is the final step in the derivation of the implementation algorithm for the Hybrid Walsh codes and derives the complex Walsh code vectors from the real Walsh code vectors by using the DFT derivation in equations **(7)** and **(9)**, by using the correspondences between the real Walsh and Fourier in equations **(6)**, and by using the fundamental correspondence

between the Hybrid ~~complex~~ Walsh and the complex DFT given in equation **(10)**. We start by constructing the ~~complex~~ Hybrid Walsh

Correspondence between ~~complex~~ Hybrid Walsh and DFT

_ ——— **(10)**

$\widetilde{W} \sim E$ NxN complex DFT orthogonal code matrix

where = NxN ~~complex~~ Hybrid Walsh orthogonal code matrix

= N rows of N chip code vectors

= [$\widetilde{W}$(u)] matrix of row vectors $\widetilde{W}$(u)

= [$\widetilde{W}$(u,n)] matrix of elements $\widetilde{W}$(u,n)

$\widetilde{W}$(u) = Complex Walsh code vector u

= [$\widetilde{W}$(u,0), $\widetilde{W}$(u,1), …, $\widetilde{W}$(u,N-1)]

$\widetilde{W}$ = +/-1 +/- j possible value

~~Walsh~~dc (0 frequency and 0 sequency) code vector $\widetilde{W}$(0). We use equation E(0)=C(0) in **43** in equations **(7)**, the correspondence in equations **(6)**, and observe that the dc complex Walsh vector has both real and imaginary components in the $\widetilde{W}$ domain, to derive the dc ~~complex~~ Hybrid Walsh code vector:

$$\widetilde{W}(0) = W(0) + jW(0) \qquad \text{for } u=0 \qquad \textbf{(11)}$$

For Hybrid ~~complex~~ Walsh code vectors $\widetilde{W}(u)$, u=1,2,…,N/2-1, we apply the correspondences in equations **(10)** between the ~~complex~~ Hybrid Walsh and DFT bases and the correspondence in equation **(6)** , to the DFT equations **43** in equations **(7)**:

$$\widetilde{W}(u) = W_e(u) + jW_o(u) \quad \text{for } u=1,2,\ldots,N/2-1 \qquad \mathbf{(12)}$$
$$= W(2u) + jW(2u-1) \quad \text{for } u=1,2,\ldots,N/2-1$$

For Hybrid ~~complex~~ Walsh code vector $\widetilde{W}(N/2)$ we use the equation $E(N/2)=C(N/2)$ **43** in equations **(7)** and the same rationale used to derive equation (11), to yield the equation for $\widetilde{W}(N/2)$.

$$\widetilde{W}(N/2) = W(N-1) + jW(N-1) \quad \text{for } u=N/2 \qquad \mathbf{(13)}$$

For ~~complex~~ Hybrid Walsh code vectors $\widetilde{W}(N/2+\Delta u)$, $\Delta u=1,2,\ldots,N/2-1$ we apply the correspondences between the ~~complex~~ Hybrid Walsh and DFT bases to the spectral foldover equation $E(N/2+\Delta u)=C(N/2-\Delta u)-jS(N/2-\Delta u)$ in equation~~s~~ **(9)** with the changes in indexing required to account for the W indexing in equations **(5)**. The equation~~s~~ ~~are~~is

$$\widetilde{W}(N/2+\Delta u) = W(N-1-\Delta eu)+W(N-1-\Delta ou) \quad \text{for } u=N/2+1,\ldots,N-1 \quad \mathbf{(14)}$$
$$= W(N-1-2\Delta u) + jW(N-2\Delta u) \quad \text{for } u=N/2+1,\ldots,N-1$$

using the notation $\Delta ei=2\Delta i$, $\Delta oi=2\Delta i-1$. These Hybrid complex Walsh code vectors in equations **(11)**, **(12)**, **(13)**, **(14)** are the equations of definition for the Hybrid complex Walsh code vectors.

An equivalent way to derive the ~~complex~~ Hybrid Walsh complex code vectors in C^N from the real Walsh basis in R^{2N} is to use a sampling technique which is a known method for deriving a

complex DFT basis in C^N from a Fourier real basis in R^N. as demonstrated in FIG. **5**.

FIG. **6B** and **6C** summarize the Hybrid Walsh implementation algorithms derived in Steps 1,2,3 for implementation as lexiocographic reordering permutations of the real Walsh code vectors and lexicographic reordering permutations of the even and odd Walsh code vectors, with the reordering lexicographically arranged with increasing sequency in agreement with the correspondence "sequency ~ frequency" for "Hybrid Walsh ~ DFT".

FIG. **6B** summarizes equations **(5),(11),(12),(13,(14)** which define the real (inphase) **168** and imaginary (quadrature) **169** reordering permutations for implementation of the Hybrid Walsh. The inphase reordering permutation **168** in FIG. **6B** is implemented as an address change of the row vectors in W to correspond to the row vectors in W_R in lexicographic ordering with increasing sequency **167**. Likewise, the quadrature reordering permutation **169** is implemented as an address change of the row vectors in W to correspond to the row vectors in W_I in lexicographic ordering with increasing sequency **167**. These reordering permutations define the Hybrid Walsh $\widetilde{W} = W_R + j\, W_I$.

FIG. **6C** reorganizes the implementation algorithm for the Hybrid Walsh in FIG. **6B** as lexicographic reordering permutations of the even and odd real Walsh code vectors defined in equations **(5),(11),(12),(13,(14)**. The real (inphase) and quadrature reordering permutations **171,172** are address changes of the even,odd real Walsh vectors with increasing sequency **170**. These reordering permutations define the Hybrid Walsh $\widetilde{W} = W_R + j\, W_I$.

2. Hybrid Walsh Implementation

Transmitter equations **(15)** describe a representative ~~complex~~ Hybrid Walsh CDMA encoding implementation algorithm for the transmitter in FIG. **1A** upon replacing the real Walsh with the Hybrid Walsh, and for the cellular network in FIG. **1B** and transmitter FIG. **6D**, and for the encoding implementation in FIG. **6A.** It is assumed that there are N ~~complex~~ Hybrid Walsh code vectors $\widetilde{W}(u)$ **44** each of length N chips similar to the definitions for the real Walsh code vectors **1** in equations **(1)**. The code vector is presented by a 1xN N-chip row vector $\widetilde{W}(u) = [\widetilde{W}(u,0), \ldots, \widetilde{W}(u,N-1)]$ where $\widetilde{W}(u,n)$ is chip n of code u. The code vectors are the row vectors of the ~~complex~~ Hybrid Walsh matrix $\widetilde{W}$. Hybrid Walsh code chip n of code vector u has the possible values $\widetilde{W}(u,n) = +/-1 +/-j$. Each user is assigned a unique Walsh code which allows the code vectors to be designated by the user symbols $u=0,1,\ldots,N-1$ for N ~~complex~~ Hybrid Walsh codes. The ~~complex~~ Hybrid Walsh code vectors $\widetilde{W}(u)$ derived in equations **(11)**, **(12)**, **(13)**, **(14)** and equivalently in FIG. **6B,6C** are summarized **44** in terms of their real and imaginary component code vectors $\widetilde{W}(u)=W_R(u)+jW_I(u)$ where $W_R(u)$ and $W_I(u)$ are respectively the real and imaginary component code vectors. As per the derivation of $\widetilde{W}(u)$ the sets of real axis code vectors $\{W_R(u)\}$ and the imaginary axis code vectors $\{W_I(u)\}$ both consist of the real Walsh code vectors in R^N with the ordering modified to ensure that the definition of the ~~complex~~ Hybrid Walsh vectors satisfies equations **(11)**, **(12)**, **(13)**, **(14)**.

~~Complex~~ Hybrid Walsh CDMA encoding for transmitter **(15)**

44 ~~Complex~~ Hybrid Walsh codes use the definitions

for the real Walsh codes in **1** equations **(1)** and the definitions of the ~~complex~~ Hybrid Walsh codes in equations **(11)**, **(12)**, **(13)**, **(14~~).~~** and in FIG. **6B,6C.**

We find

$\tilde{W}$ = ~~complex~~ Hybrid Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [$\tilde{W}(u)$] matrix of row vectors $\tilde{W}(u)$

= [$\tilde{W}(u,n)$] matrix of elements $\tilde{W}(u,n)$

$\tilde{W}(u)$ = ~~complex~~ Hybrid Walsh code vector u

= $W_R(u) + jW_I(u)$ for $u=0,1,\ldots,N-1$

where

$$
\begin{aligned}
W_R(u) &= \mathrm{Real}\{\ \tilde{W}(u)\ \} \\
&= W(0) && \text{for } u=0 \\
&= W(2u) && \text{for } u=1,2,\ldots,N/2-1 \\
&= W(N-1) && \text{for } u=N/2 \\
&= W(2N-2u-1) && \text{for } u=N/2+1,\ldots,N-1
\end{aligned}
$$

$$
\begin{aligned}
W_I(u) &= \mathrm{Imag}\{\ \tilde{W}(u)\ \} \\
&= W(0) && \text{for } u=0 \\
&= W(2u-1) && \text{for } u=1,2,\ldots,N/2-1 \\
&= W(N-1) && \text{for } u=N/2 \\
&= W(2N-2u) && \text{for } u=N/2+1,\ldots,N-1
\end{aligned}
$$

$\tilde{W}(u,n)$ = ~~complex~~ Hybrid Walsh code u chip n

= +/-1 +/-j possible values

45 Data symbols

Z(u) = Complex data symbol for user u

= $R(u) + jI(u)$

46 ~~Complex~~ Hybrid Walsh encoded data

$$
\begin{aligned}
Z(u,n) &= Z(u)\ \tilde{W}(u,n) \\
&= Z(u)[\mathrm{sign}\{W_R(u,n)\} + j\,\mathrm{sign}\{W_I(u,n)\}] \\
&= [R(u)\mathrm{sign}\{W_R(u,n)\} - I(u)\mathrm{sign}\{W_I(u,n)\}]
\end{aligned}
$$

$+ j[R(u)\,\underline{s}ign\{W_I(u,n) + I(u,n)\,\underline{s}ign\{W_R(u,n)\}]$

47 ~~**47**~~ PN scrambling

$P_2(n)$ = Chip n of the long PN code

$P_R(n)$ = Chip n of the short PN code for the real axis

$P_I(n)$ = Chip n of the short PN code for the imaginary axis

$Z(n)$ = PN scrambled ~~complex~~ Hybrid Walsh encoded data chips after summing over the users

$$= \sum_u Z(u,n)\,P_2(n)\,[P_R(n) + j\,P_I(n)]$$

$$= \sum_u Z(u,n)\,sign\{P_2(n)\}\,[sign\{P_R(n)\} + j\,sign\{P_I(n)\}]$$

= ~~Complex~~ Hybrid Walsh CDMA encoded chips

User data symbols **45** are the set of complex symbols $\{Z(u),\ u=0,1\ldots,N-1\}$. These data symbols are encoded by the Hybrid Walsh CDMA codes **46.** Each of the user symbols $Z(u)$ is assigned a unique ~~complex~~ Hybrid Walsh code $\widetilde{W}(u)=W_R(u)+jW_I(u)$. ~~Complex~~ Hybrid Walsh encoding of each user data symbol generates an N-chip sequence with each chip in the sequence consisting of the user data symbol with the complex sign of the corresponding ~~complex~~ Hybrid Walsh code chip, which means each encoded chip = [Data symbol $Z(u)$] x [Sign of $W_R(u)$ + j sign of $W_I(u)$].

The ~~complex~~ Hybrid Walsh encoded data symbols are summed and encoded with PN scrambling codes **47.** These long and short PN codes are defined **4** in equations **(1)**. ~~as a complex PN for each chip n, equal to $[P_R(u) + j\,P_I(u)]$ where $P_R(u)$ and $P_I(u)$ are the respective PN scrambling codes for the real and imaginary axes. Encoding with the complex PN is the same as given **4** in equations **(1)** for complex data symbols.~~ Each complex Walsh

encoded data chip Z(u,n) **46** is summed over the set of users u=0,1,…,N-1 and ~~complex~~ PN encoded to yield the complex Walsh CDMA chips $Z(n) = \sum_{u} Z(u,n)\ P_2(n)\ [P_R(n) + j\ P_I(n)]$ **47.**

Although not considered in this example, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA encoding in equations **(1)** since the ~~complex~~ Hybrid Walsh code vectors are a reordering of the real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axis.

Receiver equations **(16)** describe a representative ~~complex~~ Hybrid Walsh CDMA decoding implementation algorithm for the receiver in FIG. **3**A upon replacing the real Walsh with the Hybrid Walsh, and for the cellular network in FIG. **1B** and receiver FIG. **7B**, and for the decoding implementation in FIG. **7A**. . The receiver front end **48** provides estimates $\{\hat{Z}(n)\}$ of the transmitted ~~complex~~ Hybrid Walsh CDMA encoded chips {Z(n)} for the complex data symbols {Z(u)}. Orthogonality property **49** is expressed as a matrix product of the ~~complex~~ Hybrid Walsh code chips or equivalently as a matrix ~~produce~~ product of the ~~complex~~ Hybrid Walsh code chip numerical signs of the real and imaginary components. ~~The 2-phase PN codes **50** have the useful decoding property that the square of each code chip is unity which is equivalent to observing that the square of each code chip numerical sign is unity.~~ Decoding algorithms **51** perform the inverse of the signal processing for the encoding in equations **(15)** to recover estimates $\{\hat{Z}(u)\}$ of the transmitter user symbols {Z(n)} for the complex data symbols {Z(u)}.

~~Complex~~ Hybrid Walsh CDMA decoding for receiver **(16)**

48 Receiver front end in FIG. 3A provides estimates $\{\hat{Z}(n)\}$ **28** of the encoded transmitter chip symbols $\{Z(n)\}$ **47** in equations **(15)**.

49 Orthogoality property of ~~complex~~ Hybrid Walsh NxN matrix $\widetilde{W}$

$$\sum_{n} \widetilde{W}(\hat{u},n)\, \widetilde{W}'(n,u) =$$

$$\sum_{n} [\,\mathrm{sgn}\{W_R(\hat{u},n)\} + j\,\mathrm{sgn}\{W_I(\hat{u},n)\}\,][\,\mathrm{sgn}\{W_R(n,u) - j\,\mathrm{sgn}\{W_I(n,u)\}]$$

$$= 2N\ \delta(\hat{u}, u)$$

where $\delta(\hat{u}, u)$ = Delta function of $\hat{u}$ and u

= 1 for $\hat{u} = u$

= 0 otherwise

$\widetilde{W}'$ = conjugate transpose of $\widetilde{W}$

50 PN decoding property

$P(n)P(n)$ = $\mathrm{sgn}\{P(n)\}\ \mathrm{sgn}\{P(n)\}$

= 1

for $P = P_2, P_R, P_I$

51 Decoding algorithm

~~**51**~~

$$\hat{Z}(u) =$$

$$2^{-1}N^{-1} \sum_{n} \hat{Z}(n)\, sign\{P_2(n)\}\, [sign\{P_R(n)\} - j\ sign\{P_I(n)\}]^* \, [sign\{W_R(n,u)\} - j\ sign\{W_I(n,u)\}]$$

= Receiver estimate of the transmitted data symbol $Z(u)$ **45** in equations **(15)**

Although not considered in this example, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA decoding in FIG. **4** since the ~~complex~~ Hybrid Walsh code vectors are the real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axis.

FIG. **6A** ~~complex~~ Hybrid Walsh CDMA encoding is a representative implementation of the ~~complex~~ Hybrid Walsh CDMA encoding which will replace the current real Walsh encoding **13** in FIG. **1A**~~,~~ and in FIG.**1C**, and in the cellular network transmitter implementation **120**,**121** in FIG.**1C**, and is defined in equations **(15)**. Inputs are the user data symbols $\{Z(u)\}$ **52**. Encoding of each user by the corresponding ~~complex~~ Hybrid Walsh code is described in **53** by the implementation of transferring the sign +/-1+/-j of each ~~complex~~ Hybrid Walsh code chip to the user data symbol followed by a 1-to-N expander $1\uparrow N$ of each data symbol into an N chip sequence using the sign transfer of the ~~complex~~ Hybrid Walsh chips. The sign-expander operation **53** generates the N-chip sequence $Z(u,n)=Z(u)[\mathrm{sgn}\{W_R(u,n)\}+j\mathrm{sgn}\{W_I(u,n)\}]=Z(u)[W_R(u,n)+jW_I(u,n)]$ for $n=0,1,\ldots,N-1$ for each user $u=0,1,\ldots,N-1$. This complex Walsh encoding serves to spread each user data symbol into an orthogonally encoded chip sequence which is spread over the CDMA communications frequency band. The complex Walsh encoded chip sequences for each of the user data symbols are summed over the users **54** followed by PN encoding with the scrambling sequence $P_2(n)[P_R(n)-jP_I(n)]$ **55**. PN encoding is implemented by transferring the sign of each PN chip to the summed chip of the Hybrid Walsh encoded data symbols. Output is the stream of complex CDMA encoded chips $\{Z(n)\}$ **56**.

FIG. **6D** is the upgrade to the cellular network transmit CDMA encoding in FIG. **1C** using the Hybrid Walsh complex channelization codes in place of the real Walsh codes. FIG. **6D** depicts a representative embodiment of the transmitter signal processing for the forward and reverse CDMA links **106** in FIG. **1B** between the base station and the user for CDMA2000 and W-CDMA. Similar to FIG. **1C** the data inputs are the inphase data symbols R **173** and quadrature data symbols I **174**. Inphase **175** Hybrid Walsh codes W_I are implemented in FIG. **6B 167,168** and equivalently in FIG. **6C 170,171**. Quadrature **176** Hybrid Walsh codes W_I are implemented in FIG. **6B 167,169** and equivalently in FIG. **6C 170,172**. A complex multiply **177** encodes the data symbols with the Hybrid Walsh $\widetilde{W}$ codes in the encoder using the inphase (real) W_R and quadrature (imaginary) W_I code components of $\widetilde{W}=W_R+jW_I$ to generate a rate R=N set of Hybrid Walsh encoded data chips for each inphase and quadrature data symbol. Following the Hybrid Walsh encoding the transmit signal processing in **178-to-189** is identical to the corresponding transmit signal processing in **122-to-133** in FIG. **1C**.

FIG. **6D** depicts an embodiment of the upgrade to the current CDMA transmitter art using the Hybrid Walsh codes in place of the real Walsh codes and with current art signal processing changes this figure is representative of the use of Hybrid Walsh codes in place of the real Walsh codes for other current art CDMA receiver embodiments of this invention disclosure. Other embodiments of the CDMA transmitter include changes in the ordering of the signal processing, single channel versus multi-channel Hybrid Walsh encoding, summation or combining of the Hybrid Walsh channels by summation over like chip symbols, analog versus digital signal representation, baseband versus IF frequency CDMA processing, the order and placement in the signal processing thread of the Σ, LPF, and D/A signal processing operations, and the up-conversion processing. The order of the rate R=1 PN code

multiplies in FIG. **6D** can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **180,181,182** in FIG. **6D** can occur prior to the long code multiply **178,179** and moreover the long code can be complex with the real multiply **179** replaced by the equivalent complex multiply **182.**

Although not considered in ~~this~~ these examples, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA encoding in FIG. **2** since the ~~complex~~ Hybrid Walsh code vectors are the reordered real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axis.

It should be obvious to anyone skilled in the communications art that ~~this~~ the example implementations in FIG. **6A,6D** clearly define~~s~~ the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that ~~this~~ these examples ~~is~~ are representative of the other possible signal processing approaches.

FIG. **7A** ~~complex~~ Hybrid Walsh CDMA decoding is a representative implementation of ~~complex Walsh~~ CDMA complex channelization decoding which will replace the current real Walsh decoding **27** in FIG. **3A**, and is defined in equations **(15)**. Inputs are the received estimates of the complex CDMA encoded chips $\{\hat{Z}(n)\}$ **57**. The PN ~~scrambling code~~ codes ~~is~~ are stripped off from these chips **58** by changing the sign of each chip according to the numerical sign of the real and imaginary components of the complex conjugate of the PN code as per the decoding algorithm~~s~~ ~~**50**~~ **51** in equations **(16)**.

The ~~complex~~ Hybrid Walsh channelization coding is removed by a pulse compression operation consisting of multiplying each received chip by the numerical sign of the corresponding complex Walsh chip for the user and summing the products over the N Walsh chips **59** to recover estimates $\{\hat{Z}(u)\}$ of the user complex data symbols {Z(u)}.

FIG. **7B** is the upgrade to the cellular network receive CDMA decoding in FIG. **3B** using the Hybrid Walsh complex channelization codes in place of the real Walsh codes. FIG. **7B** depicts a representative embodiment of the receiver signal processing for the forward and reverse CDMA links **106** in FIG. **1B** between the base station and the user for CDMA2000 and W-CDMA that implements the CDMA decoding for the decovering by the long code and the short complex codes followed by the Hybrid Walsh decoding to recover estimates of the transmitted inphase (real) data symbols R **173** and quadrature (imaginary) data symbols I **174** in FIG. **6D**. Depicted are the principal signal processing that is relevant to this invention disclosure. Similar to FIG. **3B** the signal input $\hat{v}(t)$ **190** is the received estimate of the transmitted CDMA signal v(t) **189** in FIG. **6D**. The receive signal recovery in **191-to-201** is identical to the corresponding receive signal processing in **135-to-145** in FIG. **3B**. The decovered chip symbols are rate R=1/N decoded by the Hybrid Walsh complex decoder **204** using the complex conjugate of the Hybrid Walsh code structured as the inphase Hybrid Walsh code W_R **202** and the negative of the quadrature Hybrid Walsh code $(-)W_I$ **203** to implement the complex conjugate of the Hybrid Walsh code in the complex multiply and decoding operations. Decoded output symbols are the inphase data symbol estimates $\hat{R}$ **205** and the quadrature data symbols $\hat{I}$ **206**.

FIG. **7B** depicts an embodiment of the upgrade to the current CDMA receiver art using the Hybrid Walsh code in place of the

real Walsh code and with current art signal processing changes this figure is representative of the use of Hybrid Walsh codes in place of the real Walsh codes for other current art CDMA receiver embodiments of this invention disclosure. Other embodiments of the CDMA receiver include changes in the ordering of the signal processing, analog versus digital signal representation, down-conversion processing, baseband versus IF frequenncy CDMA processing, the order and placement in the signal processing thread of the Σ, LPF, and A/D signal processing operations, and single channel versus multi-channel Hybrid Walsh decoding, The order of the rate R=1 PN code multiplies in FIG. **7B** which perform the code decovering can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **197,198,199** can occur after to the long code multiply **200,201** and moreover the long code can be complex with the real multiply **201** replaced by the equivalent complex multiply **199.**

Although not considered in ~~this~~ these examples, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA decoding in FIG. **4** since the complex Walsh code vectors are the real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axis.

It should be obvious to anyone skilled in the communications art that ~~this~~ these example implementations in FIG. ~~6~~ **7A,7B** clearly define~~s~~ the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

For cellular applications the transmitter description describes the transmission signal processing applicable to this

invention for both the hub and user terminals, and the receiver describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.

3. Generalized Hybrid Walsh Codes using Tensor Product, Direct Sum, and Functional Combining

~~Complex orthogonal CDMA code space C^N for hybrid complex Walsh codes: The~~Generalized Hybrid Walsh codes enable the power of 2 code lengths N=2^M where M is an integer~~,~~ for ~~complex~~ Hybrid Walsh ~~can~~ to be modified to allow the code length N to be a product of powers of primes **60** in equations **(17)** or a sum of powers of primes **61** in equations **(17)**, at the implementation cost of introducing multiply operations into the CDMA encoding and decoding. In the previous disclosure of this invention we used N equal to a power of 2 which means N=2^~~m~~ M corresponding to prime $p_0 = 2$ and $M=m_0$. This restriction was made for convenience in explaining the construction of the ~~complex~~ Hybrid Walsh and is not required since it is well known that Hadamard matrices exist for non-integer powers of 2 and,

therefore, ~~complex~~ Hybrid Walsh matrices exist for non-integer powers of 2.

Length N of generalized ~~h~~Hybrid ~~complex~~ Walsh ~~orthogonal~~ codes **(17)**

60 ~~Kronecker~~ Tensor product code construction

$$N = \prod_k p_k^{m_k}$$

$$= \prod_k N_k$$

where

$\cancel{p_k}$ p_k = prime number indexed by k starting with k=0

m_k = order of the prime number p_k

N_k = Length of code for the prime p_k

$$= p_k^{m_k}$$

61 Direct sum code construction

$$N = \sum_k p_k^{m_k}$$

$$= \sum_k N_k$$

Add-only arith~~e~~metic operations are required for encoding and decoding both real Walsh and ~~complex~~ Hybrid Walsh CDMA codes since the real Walsh values are +/-1 and the ~~complex~~ Hybrid Walsh values are {+/-1 +/-j} or equivalently are {1,j,-1,-j} under a -90 degree rotation and normalization which means the only operations are sign transfer and adds plus subtracts or add-only. Multiply operations are more complex to implement than add operations. However, the advantages of having greater flexibility in choosing the orthogonal CDMA code lengths N using equations **(17)** can offset the expense of multiply operations for particular applications. Accordingly, this invention

includes the concept of generalized ~~h~~Hybrid ~~complex~~ Walsh orthogonal CDMA codes with the flexibility to meet these needs. This extended class of ~~complex~~ Hybrid Walsh codes ~~are hybrid in that their construction~~ supplement~~s~~ the ~~complex~~ Hybrid Walsh codes ~~with the use of~~by combining with Hadamard (or real Walsh), DFT, and other orthogonal codes as well as with PN by relaxing the orthogonality property to quasi-orthogonality.

Generalized Hybrid ~~complex~~ Walsh orthogonal CDMA codes can be constructed as demonstrated in **64** and **65** in equations **(18)** for the ~~Kronecker~~ tensor product, and in **66** in equations **(18)** for the direct sum, and in **67** for functional combining. Code matrices considered for orthogonal CDMA codes are **62** in equations **(18)** for the construction of the generalized ~~h~~Hybrid ~~complex~~ Walsh are the DFT E and Hadamard H, in addition to the ~~complex~~ Hybrid Walsh $\widetilde{W}$. The algorithms and examples for the construction start with the definitions **63** of the NxN orthogonal code matrices $\widetilde{W}_N$, E_N, H_N for $\widetilde{W}$, E, H respectively, examples for low orders N=2,4, and the equivalence of E_4 and $\widetilde{W}_4$ after the $\widetilde{W}_4$ is rotated through the angle -90 degrees and rescaled. The CDMA current and developing standards use the prime 2 which generates a code length $N=2^M$ where M=integer. For applications requiring greater flexibility in code length N, additional primes can be used using the ~~Kronecker~~ tensor construction. We illustrate this in **65** with the addition of prime=3. The use of prime=3 in addition to the prime=2 in the range of N=8 to 64 is observed to increase the number of N choices from 4 to 9 at a modest cost penality of using multiples of the angle increment 30 degrees for prime=3 in addition to the angle increment 90 degrees for prime=2. As noted in **65** there are several choices in the ordering of the ~~Kronecker~~ tensor product construction and 2 of these choices are used in the

construction. In general, different orderings of the tensor product yield different sets of orthogonal codes.

Direct sum construction provides greater flexibility in the choice of N without necessarily introducing a multiply penality. However, the addition of the zero matrix in the construction is generally not desirable for CDMA communications. A functional combining in **67** in equation **(18)** removes these zero matrices at the cost of relaxing the orthogonality property to quasi-orthogonality.

Construction of generalized ~~h~~Hybrid ~~complex~~ Walsh orthogonal codes **(18)**

62 Code matrices for orthogonal codes

$\widetilde{W}_N$ = NxN ~~complex~~ Hybrid Walsh orthogonal code matrix

E_N = NxN DFT orthogonal code matrix

H_N = NxN Hadamard orthogonal code matrix

63 Low-order code definitions and equivalences

2x2 $$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$= E_2$$

$$= (e^{-j\pi/4}/\sqrt{2}) * \widetilde{W}_2$$

3x3 $$E_3 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j2\pi/3} & e^{j2\pi 2/3} \\ 1 & e^{j2\pi 2/3} & e^{j2\pi/3} \end{bmatrix}$$

$$4\text{x}4 \quad H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

$$\widetilde{W}_4 = \begin{bmatrix} 1+j & 1+j & 1+j & 1+j \\ 1+j & -1+j & -1-j & 1-j \\ 1+j & -1-j & 1+j & -1-j \\ 1+j & 1-j & -1-j & -1+j \end{bmatrix}$$

$$E_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

$$= (e^{-j\pi/4}/\sqrt{2})\ \widetilde{W}_4$$

64 ~~Kronecker~~ Tensor product construction for $N=\prod_k N_k$

Code matrix C_N = NxN ~~hybrid orthogonal~~ generalized Hybrid Walsh CDMA code matrix using the ~~Kronecker~~ tensor product construction of C_N

$$C_N = C_0 \prod_{k>0} \otimes C_{N_k}$$

~~Kronecker~~ Tensor product definition

A = $N_a x N_a$ orthogonal code matrix

B = $N_b x N_b$ orthogonal code matrix

A⊗B = ~~Kronecker~~ Tensor product of matrix A and matrix B

= N_aN_b x N_aN_b orthogonal code matrix consisting of the elements $[a_{ik}]$ of matrix A multiplied by the matrix B

= [a_{ik} B]

65 Generalized Hybrid Walsh code matrix ~~Kronecker~~ Tensor product construction examples for primes p=2,3 and the range of sizes $8 \le N \le 64$

8x8	C_8	=	$\widetilde{W}_8$
12x12	C_{12}	=	$\widetilde{W}_4 \otimes E_3$
	C_{12}	=	$E_3 \otimes \widetilde{W}_4$
16x16	C_{16}	=	$\widetilde{W}_{16}$
18x18	C_{18}	=	$\widetilde{W}_2 \otimes E_3 \otimes E_3$
	C_{18}	=	$E_3 \otimes E_3 \otimes \widetilde{W}_2$
24x24	C_{24}	=	$\widetilde{W}_8 \otimes E_3$
	C_{24}	=	$E_3 \otimes \widetilde{W}_8$
32x32	C_{32}	=	$\widetilde{W}_{32}$
36x36	C_{36}	=	$\widetilde{W}_4 \otimes \widetilde{W}_3 \otimes \widetilde{W}_3$
	C_{36}	=	$\widetilde{W}_3 \otimes \widetilde{W}_3 \otimes \widetilde{W}_4$

$$48x48 \quad C_{48} = \widetilde{W}_{16} \otimes \widetilde{W}_{3}$$

$$C_{48} = \widetilde{W}_{3} \otimes \widetilde{W}_{16}$$

$$64x64 \quad C_{64} = \widetilde{W}_{64}$$

66 Generalized Hyhbrid Walsh code matrices using~~**66** Direct~~ direct sum construction for $N=\sum_k N_k$

Code matrix C_N = NxN generalized ~~hybrid~~ Hybrid Walsh orthogonal Walsh CDMA code matrix with the ~~Direct~~ direct sum construction of C_N

$$C_N = C_0 \prod_{k>0} \oplus C_{N_k}$$

Direct sum definition

A = $N_a x N_a$ orthogonal code matrix

B = $N_b x N_b$ orthogonal code matrix

$A \oplus B$ = Direct sum of matrix A and matrix B

= N_a+N_b x N_a+N_b orthogonal code matrix

$$= \left[\begin{array}{c|c} A & O_{N_a x N_b} \\ \hline O_{N_b x N_a} & B \end{array}\right]$$

where $O_{N_1 x N_2}$ = $N_1 x N_1$ zero matrix

67 Generalized Hyhbrid Walsh code matrices using functional combining with direct sum construction for $N = \sum_k N_k$

Code matrix C_N = NxN generalized Hybrid Walsh orthogonal Walsh CDMA code matrix using functional combing with direct sum construction of C_N

$$C_N = f\left(C_0 \prod_{k>0} \oplus C_{N_k} ,\ C_P \right)$$

wherein

f(A,b) = functional combining operator of A,B
= the element-by-element covering of A with B for the elements of A ≠ 0,
= the element-by-element sum of A and B for the elements of A = 0

C_P = NxN pseudo-orthogonal complex code matrix whose row code vectors are independent strips of PN codes for the real and imaginary components

It should be obvious to anyone skilled in the communications art that this ~~—~~example implementations of the generalized ~~h~~Hybrid ~~complex~~ Walsh in equations **(18)** clearly define~~s~~ the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches. For example, the ~~Kronecker~~ tensor product matrices E_N and H_N can be replaced by functionals.

For cellular applications the transmitter description which includes equations **(18)** describes the transmission signal processing applicable to this invention for both the hub and user terminals in FIG. **1B**, and the receiver corresponding to the decoding of equations **(18)** describes the corresponding receiving signal processing for the hub and user terminals in FIG. **1B** for applicability to this invention.

~~Computationally efficient encoding and decoding of complex Walsh CDMA codes and hybrid complex Walsh CDMA codes:~~ It is well known that fast and efficient encoding and decoding algorithms exist for the real Walsh CDMA codes. ~~These are documented in reference [6].~~ It is obvious that with suitable modifications these algorithms can be used to develop fast and efficient encoding and decoding algorithms for the ~~complex~~ Hybrid Walsh CDMA codes since these complex codes have real and imaginary code vectors which are from the same set of real Walsh CDMA codes.

It is well known that the ~~Kronecker~~ tensor product construction involving DFT, H, and real Walsh orthogonal code vectors have efficient encoding and decoding algorithms. It is obvious that with suitable modifications these algorithms can be used to develop fast and efficient encoding and decoding algorithms for the ~~Kronecker~~ tensor products of DFT, H. and ~~complex~~ Hybrid Walsh CDMA codes since these ~~complex~~ Hybrid Walsh codes have real and imaginary code vectors which are from the same set of real Walsh CDMA codes. It is obvious that fast and efficient encoding and decoding algorithms exist for direct sum construction and functional combining.

Preferred embodiments in the previous description is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other

embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is not to be accorded the wider scope consistent with the principles and novel features disclosed herein.

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[1] IEEE Communications magazine July 2000 Vol. 38 No. 7, Multiple Access for Broadband Networks"

[2] IEEE Personal Communications April 1998 Vol. 5 No. 2, "Third Generation Mobile Systems in Europe"

[3] TIA/EIA interim standard, TIA/EIA/IS-95-A, May 1995

[4] United States Patent 5,715,236 Feb. 3 1998, "System and method for generating signal waveforms in a CDMA cellular telephone system"

[5] United Statees Patent 5,943,361 Aug 24 1999, "System and method for generating signal waveforms in a CDMA cellular telephone system"

[6] K.G. Beauchamp's book "Walsh functions and their Applications", Academic Press 1975

DRAWINGS AND PERFORMANCE DATA

FIG. 1 CDMA Transmitter Block Diagram

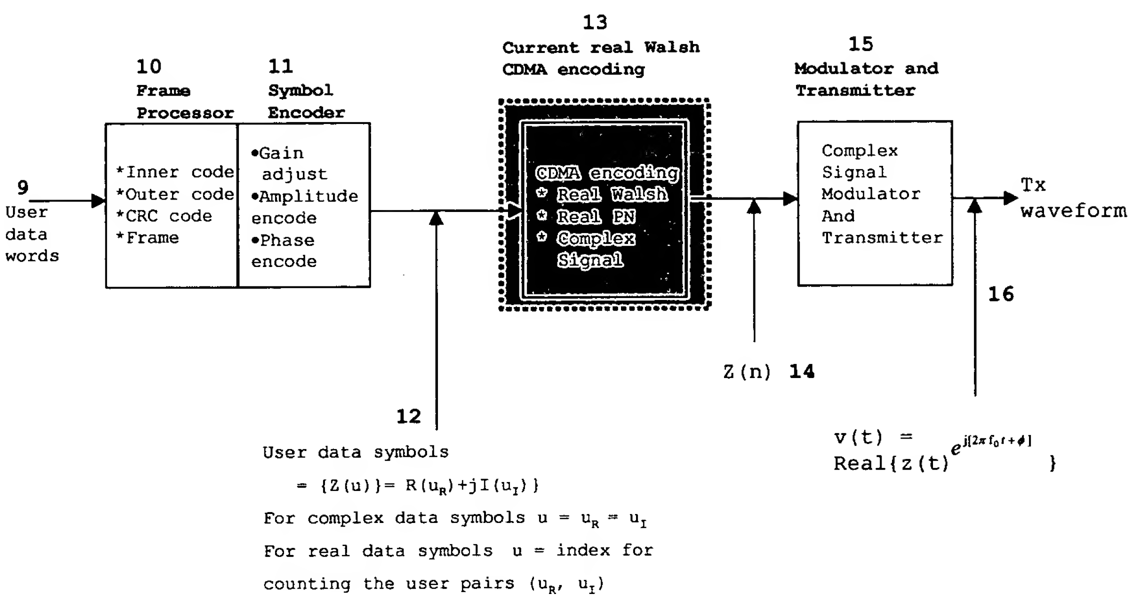


FIG. 2 Real Walsh CDMA Encoding

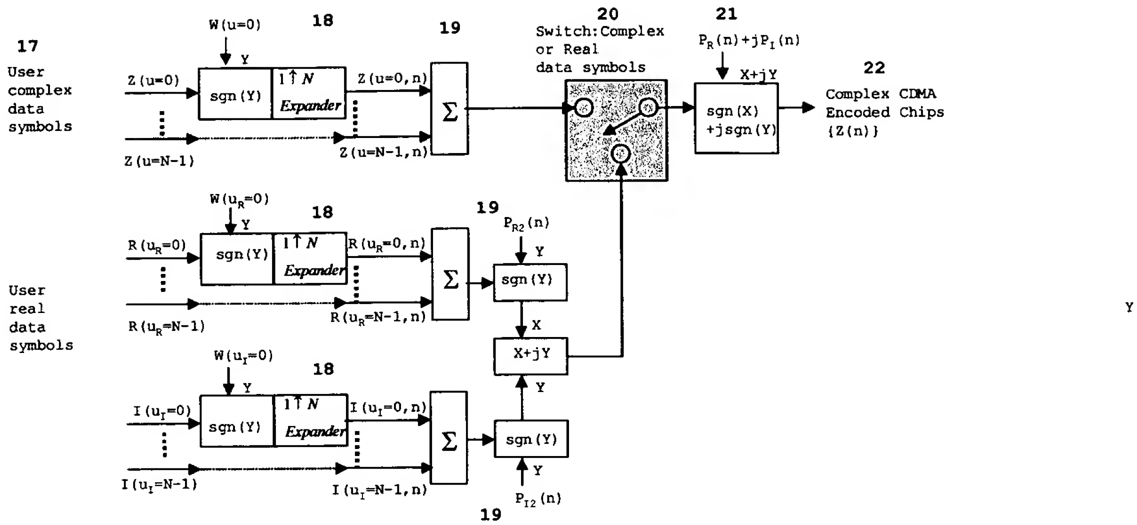


FIG. 3 CDMA Receiver Block Diagram

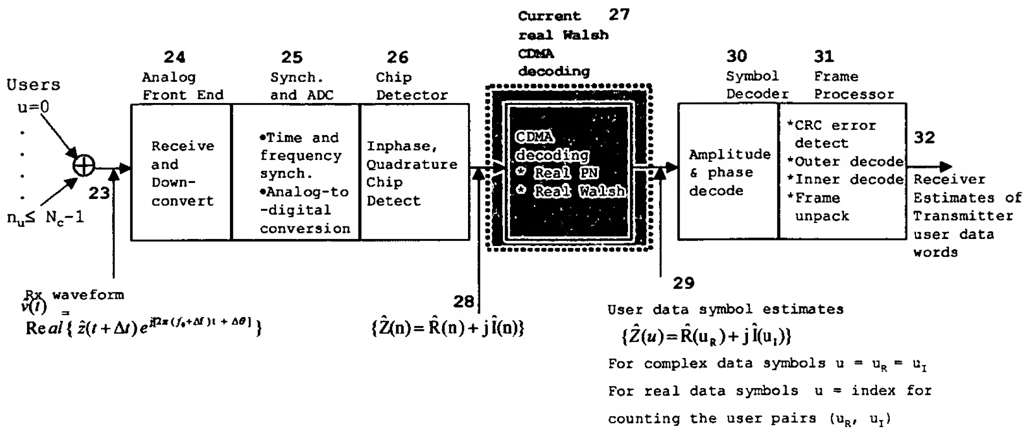


FIG. 4 Real Walsh CDMA Decoding

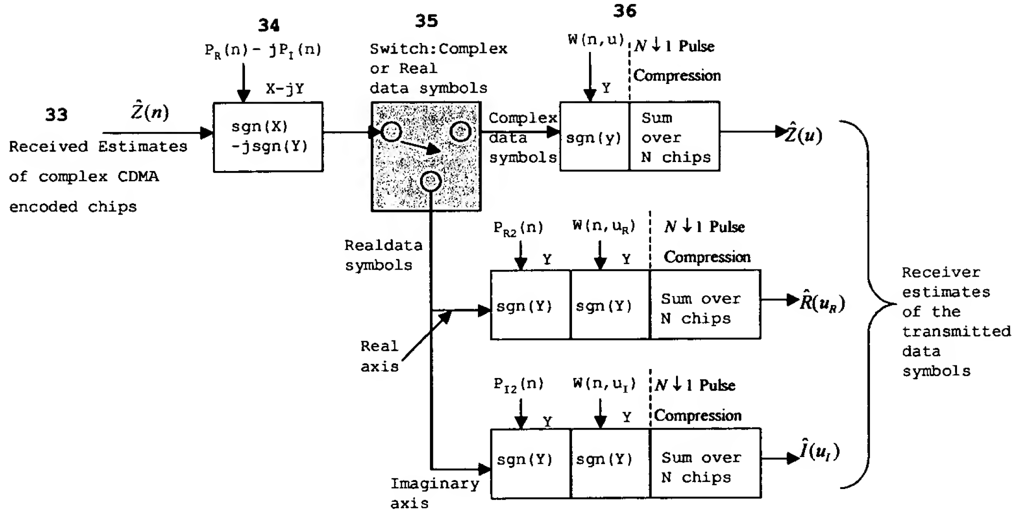


FIG. 5 Correlation of Fourier Codes with DFT Codes for N=32

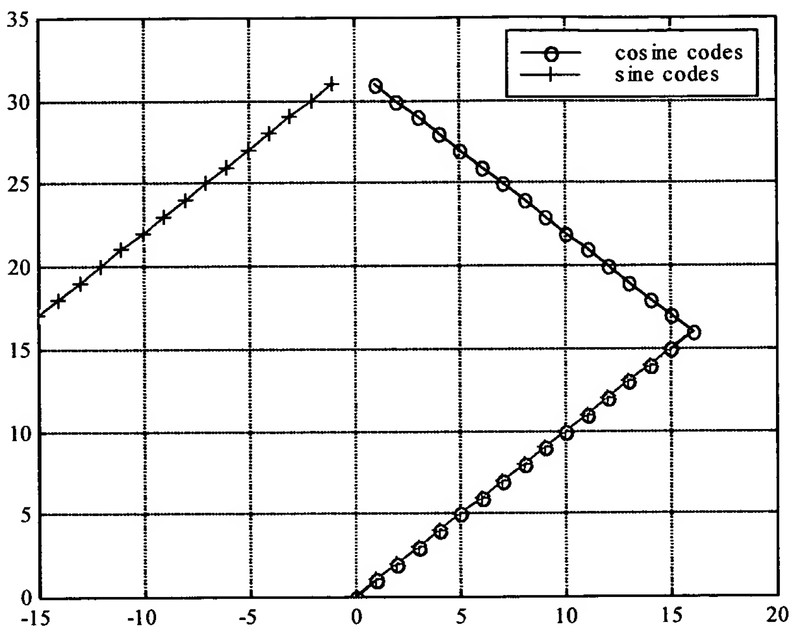
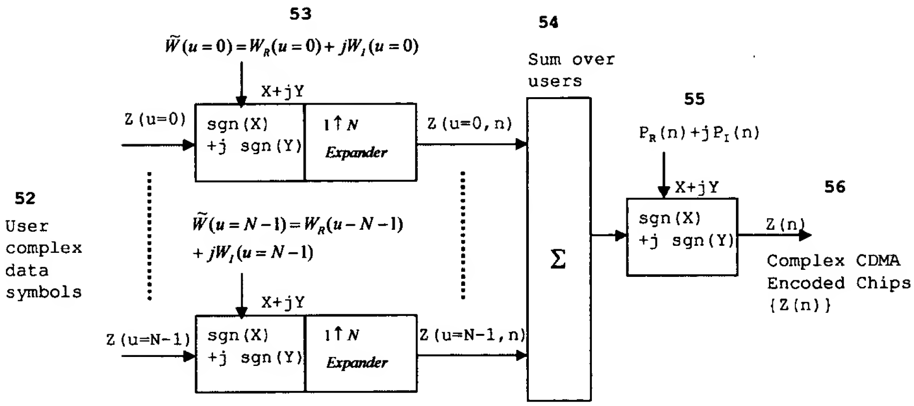
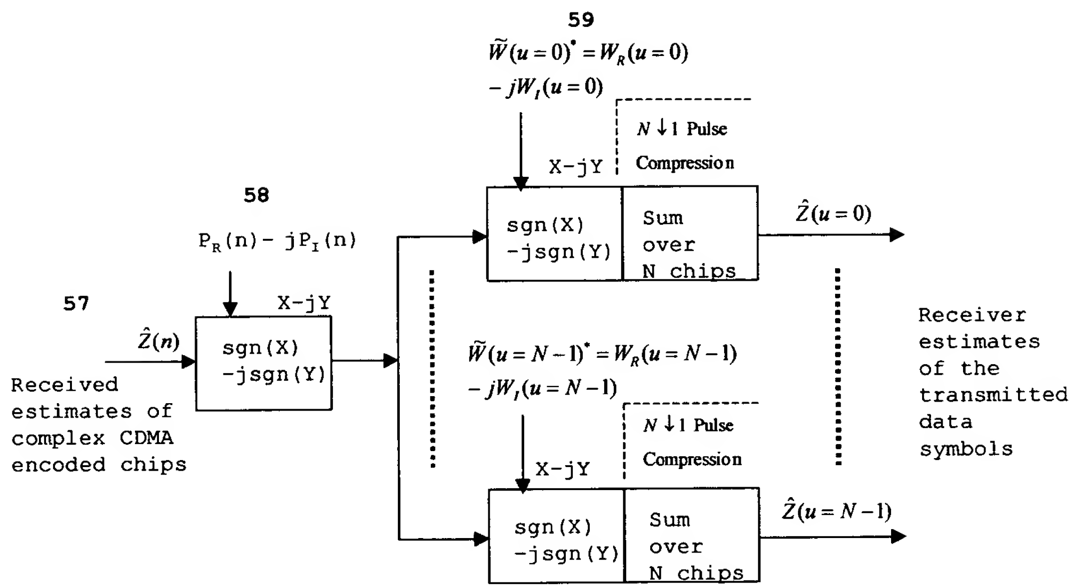


FIG. 6 Complex Walsh CDMA Encoding



Y

FIG. 7 Complex Walsh CDMA Decoding



APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hybrid ~~Complex~~ Walsh encoder and decoder ~~Codes~~ for CDMA

INVENTOR~~S~~: Urbain Alfred von der Embse

CLAIMS

WHAT IS CLAIMED IS:

~~1. A means for the design of new complex Walsh orthogonal CDMA encoding and decoding over a frequency band with properties~~

~~provide a complex Walsh orthogonal code with the real component equal to the real Walsh orthogonal code~~

~~provide a complex Walsh orthogonal code with the imaginary component equal to a reordering of the real Walsh orthogonal code, which makes the complex Walsh orthogonal code the correct complex version of the real Walsh orthogonal code to within arbitrary angle rotations and scale factors~~

~~provide a complex Walsh orthogonal code which is in correspondence with the discrete Fourier transform (DFT) complex orthogonal codes wherein the correspondence is twofold: the sequency of the complex Walsh orthogonal codes is the average rate of rotation of the complex Walsh codes and corresponds to the frequency of the DFT codes with sequency as well as frequency increasing with the code numbering, and the second correspondence is between the even and odd complex Walsh code vectors and the cosine and sine DFT code vectors respectively~~

~~provide a complex Walsh orthogonal code which has the sign values +/-1 +/-j for the real and imaginary axes~~

~~provide a complex Walsh orthogonal code which has a fast decoding algorithm~~

~~provide a hybrid complex Walsh orthogonal code which can be constructed for a wide range of code lengths by combining the complex Walsh codes with DFT complex orthogonal codes~~

~~2. A means for the design of new complex Walsh orthogonal CDMA codes with the properties~~

~~provide complex Walsh orthogonal CDMA codes which reduce to the real Walsh orthogonal CDMA codes upon removal of the complex code components~~

~~provide complex Walsh orthogonal CDMA codes which reduce to the real Walsh orthogonal CDMA codes upon removal of the real code components~~

~~provide a means for the computational efficient encoding and decoding of the complex Walsh orthogonal CDMA codes~~

~~3. A means for the design of new complex Walsh orthogonal CDMA codes with the properties~~

~~provide the correct generalization of the real Walsh orthogonal CDMA codes to the complex Walsh orthogonal CDMA codes~~

~~provide a computationally efficient means to encode and decode the complex Walsh orthogonal CDMA codes~~

~~provide a means to extend the complex Walsh orthogonal CDMA codes to include the complex discrete Fourier transform (DFT) codes to allow greater flexibility in the choices for the code lengths~~

~~4. A means for the design of hybrid complex Walsh orthogonal CDMA codes with the properties~~

~~provide a means to provide greater flexibility in the selection of the code length by combining the complex Walsh orthogonal CDMA codes with the complex DFT orthogonal CDMA codes~~

~~provide a Kronecker product means to combine the complex Walsh orthogonal CDMA codes with the complex DFT orthogonal CDMA codes~~

~~provide a direct sum means to combine the complex Walsh orthogonal CDMA codes with complex DFT orthogonal CDMA codes as well as other complex Walsh orthogonal CDMA codes~~

~~provide a functionality means to combine the complex Walsh orthogonal CDMA codes with the complex DFT orthogonal CDMA codes~~

~~5. A means for the design of 4-phase Walsh orthogonal CDMA codes with the properties~~

~~provide 4-phase Walsh orthogonal CDMA codes which can be reduced to the 2-phase real Walsh orthogonal CDMA codes~~

~~provide 4-phase Walsh orthogonal CDMA codes which are the correct generalization of the 2-phase real Walsh orthogonal CDMA codes to 4-phases~~

~~provide hybrid Walsh orthogonal CDMA codes by combining the 4-phase Walsh orthogonal codes with the N-phase DFT codes with greater flexibility in the choice of the code length~~

~~6. A means for the design of 4-phase Walsh orthogonal CDMA codes with the properties~~

~~provide 4-phase Walsh orthogonal CDMA codes in the code space C^N which include the 2-phase real Walsh orthogonal CDMA codes in R^N~~

~~provide 4-phase Walsh orthogonal CDMA codes which have computationally efficient encoding and decoding implementation algorithms~~

<u>7. A means for the design and implementation of encoders and decoders for Hybrid Walsh complex orthogonal CDMA channelization codes over a frequency band with properties</u>

<u>inphase (real) codes are equal to a lexicographic reordering permutation of the Walsh code</u>

<u>quadrature (imaginary) codes are equal to a lexicographic reordering permutation of the Walsh code</u>

<u>codes have a 1-to-1 sequency~frequency correspondence with the DFT codes</u>

codes have 1-to-1 even~cosine and odd~sine correspondences with the DFT codes

codes take values {1+j, -1+j, -1-j, 1-j}

codes take values {1, j, -1, -j} with a (-45) rotation of axes and a renormalization

codes have fast encoding and fast decoding algorithms

encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes

decoders are implemented in CDMA receivers for representative embodiments as complex conjugate transpose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes

8. A means for the design and implementation of encoders and decoders for generalized Hybrid Walsh complex orthogonal CDMA channelization codes over a frequency band with properties

codes can be constructed for a wide range of code lengths by combining with DFT and quasi-orthogonal PN codes using tensor product, direct product, and functional combining

codes can be constructed as tensor products with DFT codes and quasi-orthogonal PN codes and other codes

codes can be constructed as direct products with DFT codes and quasi-orthogonal PN codes and other codes and with functional combining

codes are complex valued

codes have fast encoding and fast decoding algorithms

encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes

decoders are implemented in CDMA receivers for representative embodiments as complex conjugate transpose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes

9. A means for the design and implementation of encoders and decoders for complex orthogonal CDMA channelization codes over a frequency band with properties

inphase (real) codes are equal to a reordering permutation of the Walsh code

quadrature (imaginary) codes are equal to a reordering permutation of the Walsh code

codes are complex valued

codes have fast encoding and fast decoding algorithms

encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes

decoders are implemented in CDMA receivers for representative embodiments as complex conjugate tanspose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes

10. A means for the design and implementation of encoders and decoders for generalized complex orthogonal CDMA channelization codes over a frequency band with properties

codes can be constructed for a wide range of code lengths by combining with DFT and quasi-orthogonal PN codes using tensor product, direct product, and functional combining

codes can be constructed as tensor products with DFT codes and quasi-orthogonal PN codes and other codes

codes can be constructed as direct products with DFT codes and quasi-orthogonal PN codes and other codes and with functional combining

codes are complex valued

codes have fast encoding and fast decoding algorithms

encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes

decoders are implemented in CDMA receivers for representative embodiments as complex conjugate transpose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes

APPLICATION NO. 09/826,117

TITLE OF INVENTION: ~~Complex~~Hybrid Walsh encoder and decoder ~~Codes~~ for CDMA

INVENTOR~~S~~: Urbain Alfred von der Embse

ABSTRACT OF THE DISCLOSURE

The ~~present~~ invention provides a method and system for the generation of Hybrid ~~describes a new set of complex~~ Walsh ~~and hybrid complex Walsh~~ orthogonal codes for CDMA spreading and channelization encoding and fast decoding. Current art uses real ~~2-phase~~ Walsh orthogonal codes for CDMA spreading and orthogonal channelization. ~~encoding of the data for the CDMA signal. Complex CDMA is widely known to be better than real CDMA and the current art generates complex CDMA by using real Walsh codes together with pseudo-noise bi-phase (PN) codes to generate a complex CDMA signal. The new 4-phase complex Walsh orthogonal CDMA codes provide fundamental performance improvements which include an increase in the carrier-to-noise ratio (CNR) for data symbol recovery in the receiver, lower correlation side-lobes under timing offsets both with and without PN spreading, lower levels of harmonic interference caused by non-linear amplification of multi-carrier CDMA signals, and reduced phase tracking jitter for code tracking to support both acquisition and synchronization.~~ Hybrid Walsh codes are complex Walsh codes that have a isomorphic one-to-one correspondence with the discrete Fourier transform (DFT) codes and are derived by separate permutations of real Walsh codes for the real and for the imaginary components. Hybrid Walsh codes are the best approximation to the DFT within the constraints of a unity norm, 4-phases on real and imaginary axes, orthogonality, and therefore are a preferred choice for a complex Walsh code. ~~Hybrid complex~~

~~Walsh orthogonal CDMA codes increase the choices for the code length by allowing the combined use of complex Walsh and discrete Fourier transform complex orthogonal codes~~ The invention discloses a method for the Hybrid Walsh encoder to be generalized by combining with DFT, quasi-orthogonal PN codes, and other codes using a ~~Kronecker~~ tensor product construction, direct sum constructioin, and ~~as well as the possibility for more general~~ functional combining.